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Draft A

100-NR-2 Groundwater Operable Unit Phytoextraction Treatability Test Plan

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

U.S. DEPARTMENT OF ENERGY Richland Operations Office

P.O. Box 550
Richland, Washington 99352

Approved for Public Release;
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Terms

ALARA	as low as reasonably achievable
ARAR	applicable or relevant and appropriate requirement
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
Ci	Curies
CMS	corrective measures study
COC	contaminant of concern
CR	Concentration Ratios
DOE	U.S. Department of Energy
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ERA	expedited response action
ERDF	Environmental Restoration Disposal Facility
gpm	gallons per minute
HEPA	high-efficiency particulate air (filter)
ITRD	Innovative Treatment and Remediation Demonstration
FS	feasibility study
FY	fiscal year
K_d	high adsorption coefficient
L/min	liters per minute
LFI	Limited Field Investigation
LWDF	liquid waste disposal facility
mCi	milliCuries
MNA	monitored natural attenuation
NEPA	National Environmental Policy Act
NPL	National Priorities List
NSCC	nonselective cation channels
OU	operable unit
pCi	picoCuries

PNNL	Pacific Northwest National Laboratory
PRB	Permeable Reactive Barrier
PVC	polyvinyl chloride
QRA	qualitative risk assessment
RAO	remedial action objective
RI	Remedial Investigation
ROD	Record of Decision
RWP	radiological work permit
Sr	strontium
TAG	Technical Advisory Group
Tri-Party Agreement	*Hanford Federal Facility Agreement and Consent Order*
TTP	treatability test plan
WMP	Waste Management Plan

1 Introduction

This document presents a treatability test plan (TTP) for placement of a phytoextraction test plot in the riparian zone of the Columbia River along the shoreline located in the 100-NR-2 Operable Unit (OU) at the Hanford Site near Richland, Washington. Figure 1 shows the location of the Hanford Site within Washington State and the location of 100-N within the Hanford Site. The phytoextraction test plot will determine the efficacy of using plants, specifically coyote willow (*Salix exigua*), to extract strontium-90 (Sr-90) from the river shoreline. It will do this while assisting the newly emplaced apatite permeable reactive barrier (PRB) in the prevention of Sr-90 migration into the Columbia River from contaminated groundwater and near shore sediments. This TTP describes the historic and current activities associated with 100-N that led to the presence of Sr-90 contamination in the groundwater and sediments next to the river as well as the efforts to remove the contaminant. The scientific basis for the application of growing plants to extract Sr-90 from soil will be detailed, along with previous research efforts, to demonstrate its potential at the 100-N shoreline. The location and requirements (materials and procedures) for placement of the test plot will be presented along with the anticipated criteria to be met to determine the success of the initial plantings and if this technology would be appropriate for a site-wide deployment. Figure 2 shows the location of the test plot within 100-N. This work is being performed under the *Interim Remedial Action Record of Decision for the 100-NR-1 and 100-NR-2 Operable Units* (EPA/ROD/R10-99/112) to fulfill the interim remedial action objective (RAO) of evaluating alternative treatment technologies.

1.1 Historical Basis for the Treatability Test Plan

From 1943 to 1986, the 100 Area (located along the Columbia River) contained nine U.S. Department of Energy (DOE) nuclear reactors used for plutonium production. The last operable reactor (1963 to 1986) was the 100-N Reactor, also shown in Figure 1. The operation of the N Reactor required the management and/or disposal of the cooling water that periodically bled from the reactor's primary cooling loop, the spent fuel storage basins, and other reactor-related sources. Two crib and trench liquid waste disposal facilities (LWDFs) were constructed to receive reactor-related waste streams. Disposed contaminated wastewater percolated into the soil of the trench. The first of these, LWDF 1301-N (now managed as the 116-N-1 waste site), is shown in Figure 2. It was constructed in 1963 and was placed about 244 m (800 ft) from the river. Liquid discharges to this facility contained radioactive fission and activation products, including cobalt-60 (Co-60), cesium-137 (Cs-137), Sr-90, and tritium. The waste stream also contained dangerous wastes including sodium dichromate, phosphoric acid, lead, and cadmium.

The cooling discharges occurred at a rate of approximately 7,950 liters per minute (L/min) (2,100 gallons per minute [gpm]). Over time, this caused the water table to rise approximately 9.1 m (30 ft) underneath the LWDFs, creating a large groundwater mound with a concomitant steeper groundwater gradient toward the Columbia River (Connelly et al, 1997). Monitoring wells, installed between the LWDF and the Columbia River at the start of operations, identified mobile contaminants (i.e., tritium) almost immediately at springs (seeps) located at that time along the 100-N shoreline. In 1980, the monitoring system detected Sr-90 near the river. In 1983, the detection of Sr-90 prompted the construction of a second LWDF (1325-N/116-N-3 waste site) farther inland, about 670 m (2,200 ft) from the river (not shown in Figure 2). Following this, disposal at the first LWDF was eventually terminated. Discharges to the 1325-N LWDF ceased in 1993 (BHI-00368). As a result of wastewater disposal practices over this period, soil contamination extended from the surface down to sediments within the unconfined aquifer and then to the Columbia River following natural groundwater flow. The *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan, Addendum 5: 100-N Decision Unit* (DOE/RL-2008-46-ADD5) presents a more complete history of the groundwater contamination at 100-N.

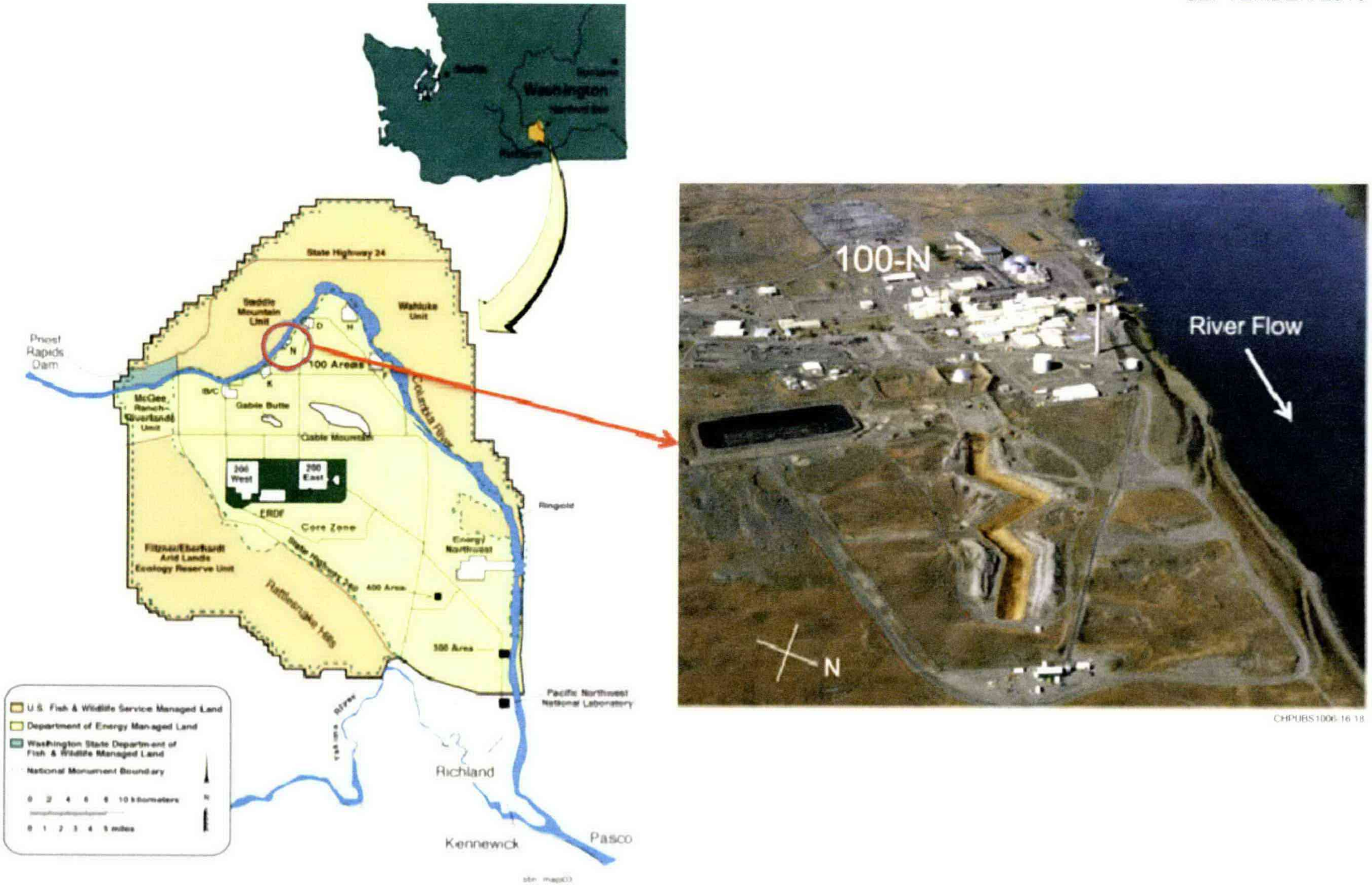

Figure 1. Diagram Showing the Location of the Hanford Site Within Washington State and 100-N Within the Hanford Site

Figure 2. Diagram Showing the Location of Phytoextraction Test Plot Within 100-N

1.2 Remediation Efforts

This section describes the formal remediation responses to the presence of Sr-90 contamination following cessation of production operations at the 100-N reactor.

The 100-N area was placed on the National Priorities List (NPL) in 1989 according to "National Oil and Hazardous Substances Pollution Contingency Plan" (40 CFR 300). During that same year, DOE, the U.S. Environmental Protection Agency (EPA), and the Washington State Department of Ecology signed the Tri-Party Agreement (Ecology et al., 1989a), which established the procedural framework and schedule for remedial response actions at the Hanford Site. The extensive subsurface contamination and National Environmental Policy Act (NEPA) process prompted the division of the Site into two OUs. The 100-NR-1 OU contains all the source waste sites located within the main industrial area around the 100-N Reactor and the Hanford Generating Plant, and includes the surface and subsurface sediments immediately associated with the LWDFs. The second OU, 100-NR-2, contains the contaminated aquifer beneath the 100-NR-1 OU. In 1994, the *Limited Field Investigation Report for the 100-NR-2 Operable Unit* (LFI) (DOE/RL-93-81) was published and a qualitative risk assessment (QRA) was conducted based on the data found. The QRA indicated that groundwater contaminants in the 100-NR-2 OU exceeded human health risk levels, which prompted an Expedited Response Action (ERA) to address Sr-90 in groundwater.

In 1995, *Corrective Measures Study for the 100-NR-1 and 100-NR-2 Operable Units* (CMS) (DOE/RL-95-111) was conducted to support the selection of remedial alternatives to address contamination at the 100-NR-1 and 100-NR-2 OUs. The study determined there was insufficient information available to choose a final groundwater remedy at 100-N. A pump-and-treat system was selected because it was expected to provide a hydraulic barrier, while removing Sr-90 from extracted groundwater, and did not preclude any potential final remedies. The 100-NR-2 OU pump-and-treat system was subsequently completed in August 1995 and was at full operation by September 1995, meeting the Tri-Party Agreement Milestone M-16-12D (Ecology et al., 1989a). Later recommendations in the *N Springs Expedited Response Action Performance Evaluation Report* (DOE/RL-95-110) prompted the upgrade of the system to operate at 227 L/min (60 gpm) beginning on December 17, 1996. The results from the CMS and the Tri-Parties' preference for interim remedial action were summarized in the *Proposed Plan for Final Remedial Actions at the 100-NR-1 Source Sites Operable Unit and Interim Remedial Action at the 100-NR-2 Groundwater Operable Unit* (DOE/RL-96-102) that was made available to the public in March 1998.

An Interim Action Record of Decision (ROD) for the 100-NR-2 OU (EPA/ROD/R10-99/112) was signed by DOE, Ecology, and EPA in September 1999. This ROD continued the operation of the pump-and-treat system while requiring the evaluations of alternative Sr-90 treatment technologies. In compliance with this requirement, a comprehensive review was conducted under the DOE Innovative Treatment and Remediation Demonstration (ITRD) program. A Technical Advisory Group (TAG) was formed under this program in 2001 (ITRD, 2001). The group evaluated several technologies and recommended continued evaluation of four technologies: monitored natural attenuation (MNA), impermeable barriers, stabilization by phosphate injection (a permeable reactive barrier [PRB]), and phytoremediation (FH-0403540).

Further technology screening led to the decision that barrier walls constructed via trenching would not be feasible along the shoreline. In addition, MNA would not limit current discharges of Sr-90 to the river. Stabilization by phosphate injection (a PRB) was considered the primary approach while phytoremediation was retained for consideration in conjunction with a PRB barrier, but was not regarded as a stand-alone solution for the near-shore area.

1.3 Phytoremediation

This section provides some of the attributes of phytoremediation that have permitted its continued evaluation as a potential remediation technology at 100-NR-2 OU.

Phytoremediation, or more specifically phytoextraction, is an engineered remediation technology in which plants, or integrated plant/rhizosphere systems, are used to extract and/or sequester soil contaminants in place (Pilon-Smits, 2005; Pulford and Watson, 2003; INEEL/EXT-2000-00207). Phytoextraction of Sr-90 has been reported as a potential method to remediate radioactively contaminated sites (Willey and Collins, 2007; Vandenhove, 2006; Dutton and Humphreys, 2005). Consequently, work was initiated at Pacific Northwest National Laboratory (PNNL) in 2004 to determine the feasibility for Sr-90 phytoextraction. These efforts demonstrated that the coyote willow (*Salix exigua*) could rapidly accumulate Sr-90 from 100-N sediment (PNNL-16714), could provide sufficient biomass under field conditions (PNNL-19120), and would not become a secondary source of contaminant to the environment (PNNL-18294). Remaining is the demonstration that the willows would be as effective at the shoreline of 100-N, the actual site of the contamination.

2 Project Description

This Chapter provides background information on the site, current known contaminant locations and form, and existing and potentially interacting treatment technologies being deployed at this time and in the near future.

2.1 Nature of Strontium-90 Contamination

Strontium-90 has a half-life of 29.1 years. Therefore, it will take approximately 300 years for the Sr-90 present in the subsurface of 100-N to decay to the drinking water standard (8 picoCuries per liter [pCi/L]). A thorough literature search places the total curies of Sr-90 discharged to the LWDFs at 2998 (UNI-3533, *Closure and Post-Closure Plan for the 1301-N and 1325-N Liquid Waste Disposal Facilities*; Connelly et al., 1997). A 2003 report indicated that the majority of the 1,500 Ci of Sr-90 remaining in the unsaturated and saturated zones in 100-N is present in the vadose zone above the aquifer (DOE/RL-2004-21). An estimated 72 Ci of Sr-90 are contained in the saturated zone soils, approximately 0.8 Ci is in the groundwater, and 1,427 Ci are in the vadose zone from the LWDFs (largely directly below the LWDFs) to the shoreline. Data from soil borings collected along the riverbank indicate that Sr-90 concentrations in soil reach a maximum near the mean water table elevation and then decrease with depth

(BHI-00185). The actual amount of Sr-90 present on the sediment within the riparian zones along the river shoreline is unknown. Estimates based on analysis of samples taken from cores made during drilling activities differ greatly. Estimates range from 0.2 to less than 2.0 Ci because of the heterogeneity of the subsurface. The lower values are considered more probable.

Variations in vertical contaminant distribution are also reflected in depth-discrete groundwater concentration data. Because Sr-90 has a much greater affinity for sediment than water (high adsorption coefficient [K_d]), its rate of transport in groundwater to the river is considerably slower than the actual groundwater flow rate. The relative velocity of Sr-90 to groundwater is approximately 1:100. In 2001, before the onset of current remediation actions, the annual flux of Sr-90 was thought to be approximately 0.14 to 0.19 Ci /year (ITRD, 2001). This estimate was based on groundwater modeling, and was similar to an estimate made earlier (DOE/RL-94-132).

2.2 Apatite Permeable Reactive Barrier

This section briefly describes the primary remediation approach now underway at the shoreline of 100-N. Specific details of the process are published elsewhere (PNNL-18303, PNNL-SA-70033, and DOE/RL-2009-54).

The primary treatment plan proposed to prevent Sr-90 migration to the river at 100-N is the placement of an apatite PRB through the injection of a calcium-citrate-phosphate solution into the shoreline at the base of the bluff. The injected citrate would biodegrade, resulting in the formation of hydroxyl-apatite [$Ca_6(PO_4)_{10}(OH)_2$] to which the Sr-90 would adsorb and ultimately replace the calcium in the apatite structure. A low calcium-citrate-phosphate concentration solution for apatite formation was injected into the shallow aquifer in 10 injection wells during fiscal year (FY) 2006 and FY 2007.

The results and experience from the low-concentration injections led to the design for a series of higher concentration injections. During the summer of 2008, 16 wells were injected using adjusted techniques and chemical mixes. Much of the subsequent monitoring data is encouraging and shows that apatite is being formed and Sr-90 is being adsorbed, as designed. Based on gross beta, concentrations of Sr-90 fell below baseline levels in 19 of the 20 wells. Data indicate that Sr-90 in the one remaining well, while still exhibiting levels above baseline minimum values, is on a downward trend.

2.3 Previous Phytoextraction Testing

A successful application of phytoextraction as a treatment strategy to remove the Sr-90 contaminant within the riverbank/riparian zone at 100-N would require a demonstration of five factors:

1. The ability of plant roots to accumulate Sr at levels much higher than those present in the plant rhizosphere and transport it to other (aboveground) portions of the plant, permitting the removal of the contaminant from the shoreline
2. No discrimination in uptake between molecular Sr and Sr-90
3. A low probability of herbivore access to the plants, and where access prevention is not possible, a low potential for contaminant bioaccumulation and subsequent food chain transfer
4. Proof that the selected plant species can survive in the diverse environmental conditions that exist on the 100-N shoreline
5. The production of sufficient biomass annually to remove a significant amount of the contaminant within a time span of 10 to 20 years

The riverbank along 100-N is dominated by coarse-grained sands, subjected to significant daily fluctuations in groundwater level, and covered with a coarse cobble and boulder riprap fill. In this environment, implementation of a phytoextraction strategy would require both a plant with roots capable of invading the saturated zone, and one with an inherent ability to tolerate water table fluctuations. Coyote willow (*Salix exigua*) is a recognized component of the vegetation naturally occurring in the riparian zones along the Columbia River in the Hanford Site (WCH-EP-0554, *Vascular Plants of the Hanford Site*). The root system of the tree readily invades the saturated zone and tolerates prolonged flooding. Similar species, *Salix viminalis* (basket willow), and *Salix dasyclados*, have been used in Europe and the United States as a bioenergy source because of their rapid growth potential (von Fricks et al., 2002; Adegbidi et al., 2001). Biomass yields from plantations of the latter species have been as high as 30 metric tons per hectare (mT/ha) (33 tons/acre [T/ac]) (Adegbidi et al., 2001).

Six years of laboratory, greenhouse, and field studies in non-contaminated Columbia River riparian zones, as well as earlier studies, have shown that for coyote willow, as in other plants, calcium (Ca) and strontium (Sr) share the same uptake mechanisms and will be accumulated by the plant at the same ionic ratio that the roots encounter in the rhizosphere soil solution (Collander, 1941; Jacobson and Overstreet, 1947, 1948; Francis, 1978; PNNL-16714). Calcium and Sr are primarily transported from the root to the shoot within the xylem sap of the vascular tissues of plants (Paasikallio et al., 1994).

Coyote willows grown in sediment from 100-N do not discriminate between Sr and Sr-90 (PNNL-16714; PNNL-19120). Further, when grown in hydroponic solutions amended with Sr-90, the willows partition almost 88 percent of the assimilated Sr-90 into the aboveground (stem and leaves) portion of the plant (PNNL-16714).

A three-year field test in a non-contaminated Columbia River riparian zone (100-K West, Figure 3) demonstrated that engineered fencing could prevent large and small herbivore intrusion and subsequent access to the plants (PNNL-19120). However, herbivorous insects do have the potential to penetrate most fencing. In response, laboratory studies conducted to date with sucking (aphid) and juvenile to adult (moth larvae) insects have demonstrated insignificant potential for offsite, or food-chain transfer of Sr-90 from coyote willows growing in 100-N sediment (PNNL-18294).

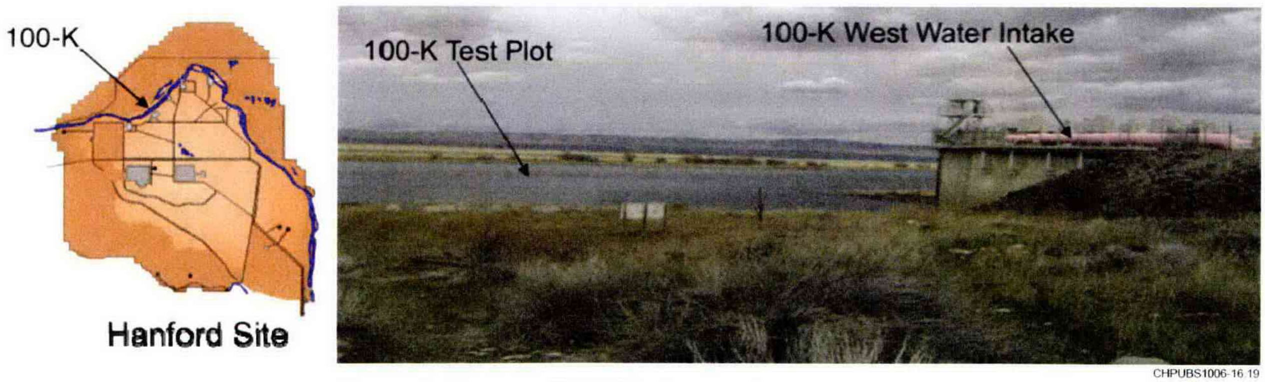

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Figure 3. Biomass Field Plot Located at 100-K West

The field test also confirmed that coyote willows could survive daily and seasonal variations in river level as well as periodic and extended (months) flooding and produce significant biomass. Plot yields were 0.2 mT/ha (0.22 T/ac) in 2007, 0.87 mT/ha (0.95 T/ac) in 2008, and 4.3 mT/ha (4.7 T/ac) in 2009 as the plants entered the logarithmic portion of the growth curve. Growth curve extrapolation predicted 13.2 mT/ha (14.5 T/ac) during a fourth year and potentially 29.5 mT/ha (32.5 T/ac) following a fifth year as shown in Figure 4.

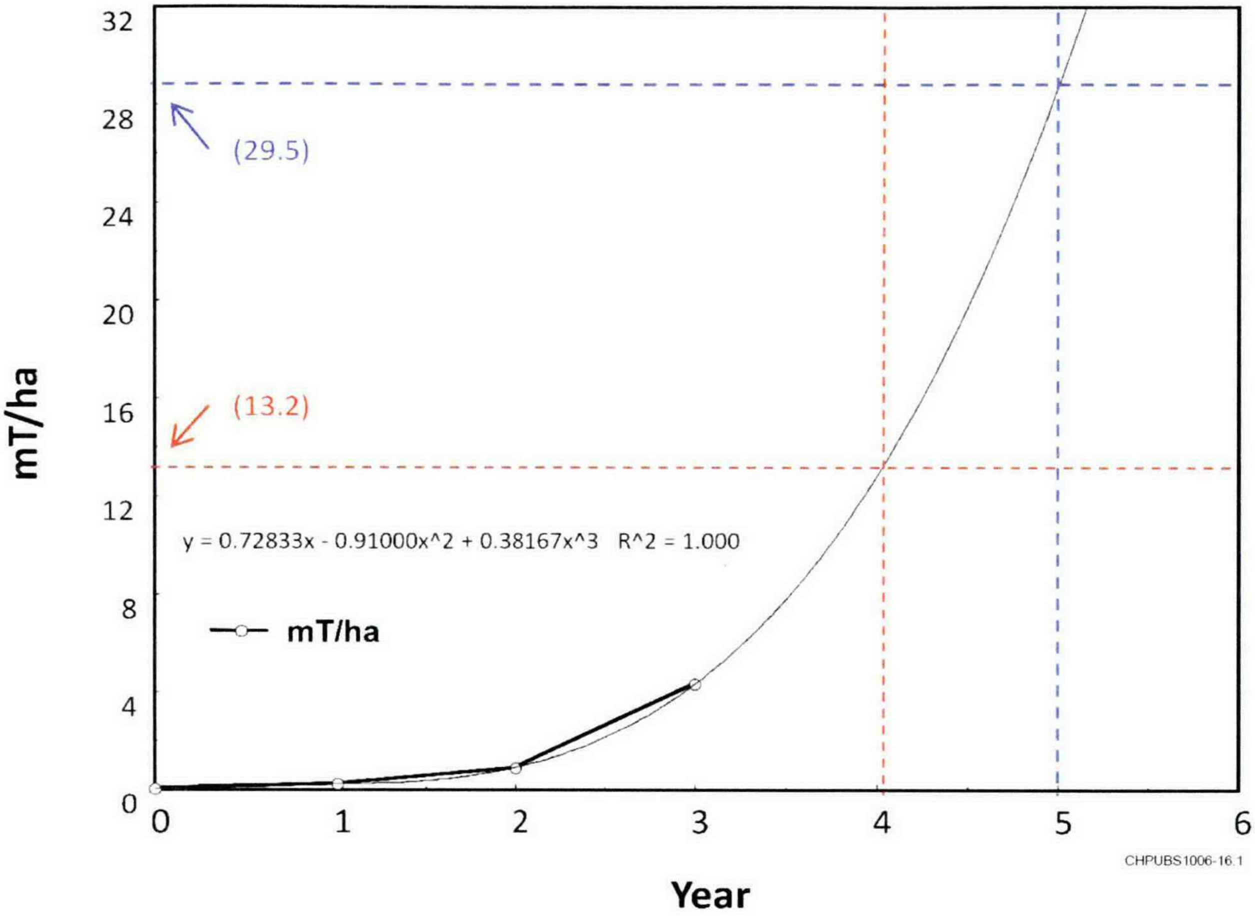


Figure 4. Graph of 100-K West Plot Yield on a mT/ha Basis Extrapolated for a Fourth and Fifth Year

2.4 100-NR-2 Phytoextraction Test

This section describes the principal goals for the trial phytoextraction project on the riparian shoreline at 100-N, and the means by which these will be met.

This field test will determine whether phytoextraction technology at 100-N shoreline can achieve the following goals:

- Indication of the approximate number of plants required to produce sufficient annual biomass
- Confirmation that the plant roots will reach the contaminated sediment near the saturated zone and accumulate sufficient Sr-90 in the stems and leaves
- Production and collection of sufficient biomass to remove greater than 10 to 15 milliCuries (mCi) of Sr-90 from the shoreline annually

The previous field trial at 100-K West was a managed plot in that the plants were evenly spaced, protected from herbivores, and received periodic fertilization to supplement the nutrients present in the sediment. While the sediment was similar in composition to that found at the 100-N shoreline, and the environments (i.e., daily water level changes and seasonal flooding episodes) were the same, the physiographic features of the two sites differ. At 100-K, the surface had a slope of less than 10 degrees (°)

toward the river while at the Site at 100-N (Figure 5), the bank has two distinct slopes, as shown in Figure 6. The first slope, immediately descending from the shore road is close to 40° and extends for about 3.7 m (12 ft). The second, more gradual slope of about 20° extends into the water for 7.4 m (24 ft) (Figure 6). Also, instead of the uniform cobble at 100-K, the cobble at 100-N is larger in average diameter 15 cm (6 in.) and transitions into small to medium boulder-sized riprap 30 to 76 cm (12 to 30 in.) in diameter.

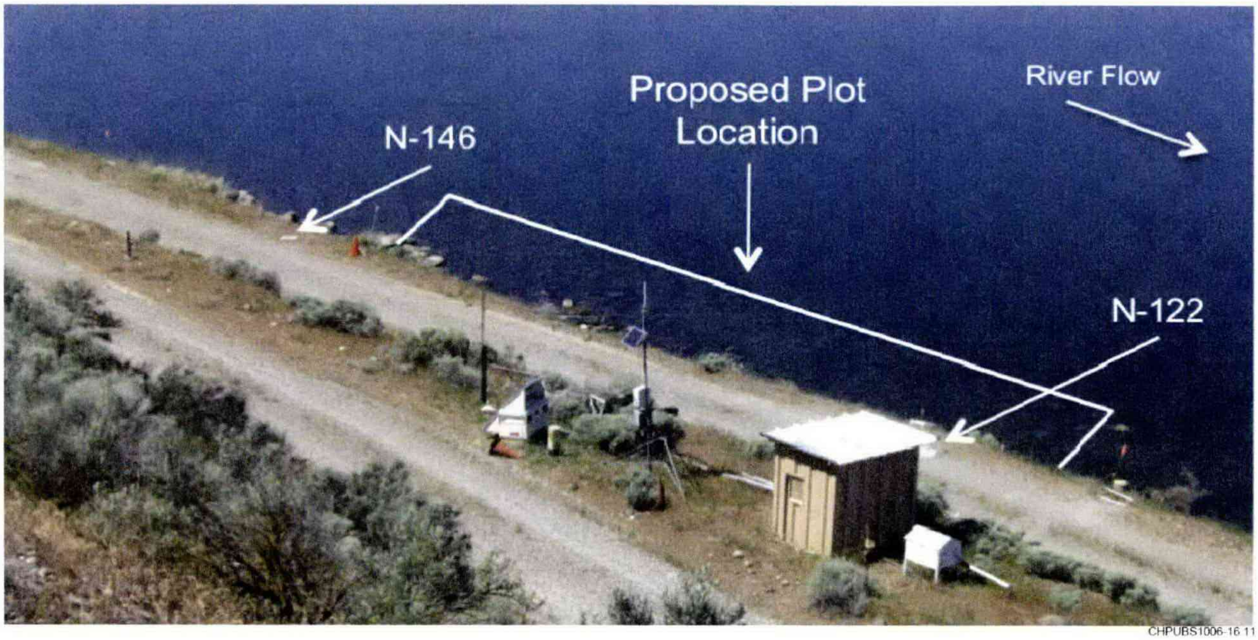


Figure 5. Location of Phytoextraction Plot in Relation to Sampling Wells 199-N-146 and 199-N-122 Along the River's Shore at 100-N

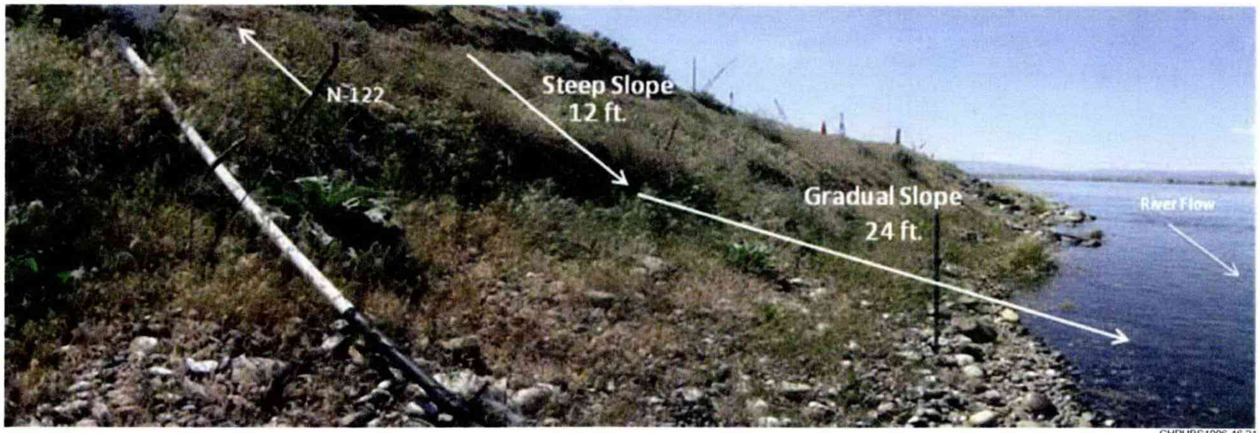


Figure 6. Photographs of 100-N Riparian Zone Phytoextraction Test Area Bank Showing the Slopes that Compose the Area

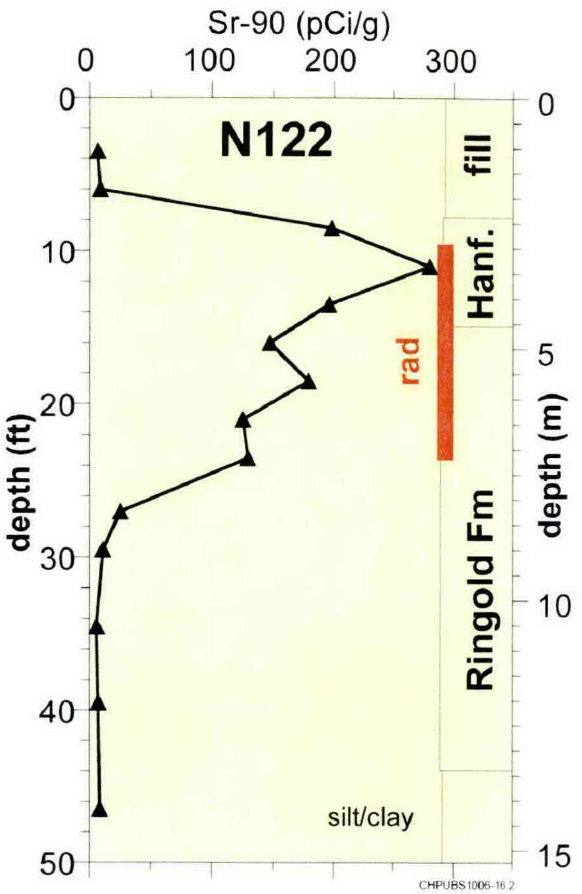


Figure 7. Diagram of Bank Profile and Sr-90 Content at Well 199-N-122 at the Roadside Above the Plot Site

As shown in Figure 7, the fill placed over the original bank can be greater than or equal to (≥) 1.5 m (5 ft) in depth on the roadway just beyond the edge of the slope at Well 199-N-122 well. The fill, in addition to being an impediment to the placement of the plants, is also a potentially significant safety hazard to workers tending to the plants. The riprap, added to the site to limit exposure from groundwater seeps, must remain in place. Therefore, commercially available assembled portable walkways are planned to be placed both down the bank and along the shoreline parallel to the river. These would be similar in appearance to those shown as examples in Figure 8 and would allow safe access up and down the banks as well as alongside the plantings. The walkways and fencing could be removed at the end of the study, returning the bank to its original state. Chapter 5 provides placement, planting, maintenance, and harvesting procedure details.

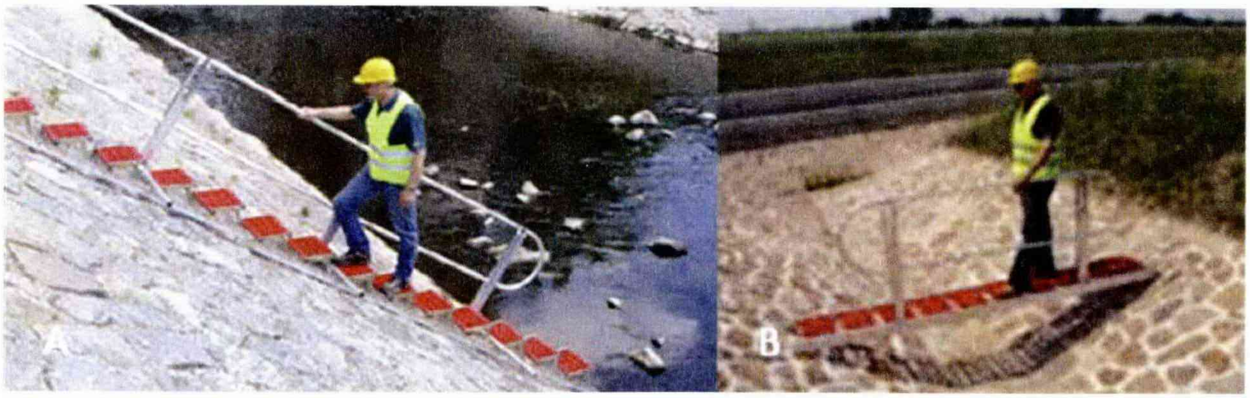


Figure 8. Example Photographs A and B, of Commercially Available Walkways and Stairways that Could be Assembled on the Slope and Shoreline of the Plot

At the 100-K site, the plants were directly hammered into the sediment to a depth of 45 to 60 cm (18 to 24 in.). With the larger cobble at 100-N, a 6.4 cm (2.5-in.) diameter pipe is driven to a surface depth of greater than 60 cm (2 ft). Then the plant cutting is extracted and slid into the hole. The lower portion of the cutting itself (about 2 cm [0.75-in.] diameter) will be encased in a 2.0-in.-diameter polyvinyl chloride (PVC) pipe 0.6 m (2.0 ft) in length. The cutting will occupy one-half to three-quarters of the length of the pipe with 100-N soil filling the remainder (Figure 9). The function of the PVC pipe will be to force root growth in a downward direction toward the contaminated sediment layer. A diagram of this assembly as it might look after one growing season is shown in Figure 10. The plot would contain 100 willow plants in five rows of 20 plants each. Preferred planting dates would be in the fall or winter when the leaves have dropped and the plant is dormant.

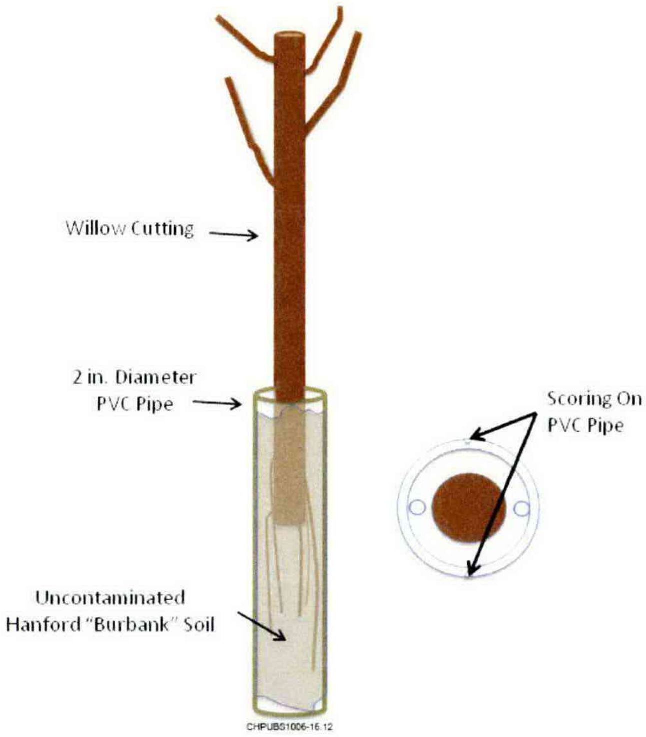


Figure 9. Diagram of Rooting Coyote Willow Cutting and Native Soil

Figure 10 depicts a willow plant's movement of roots into the Hanford layer after one year of being directed downward by the PVC pipe around the plant stem. Once established, the plants would be harvested just prior to leaf drop in the fall. Harvesting would include removal of leaves and the newly emergent stems from that growing season. Stems would be cut back to the second or third node (leaf trace scar) proximal to the main stem to provide starting points for the next season's growth. The material from each plant would be bagged and transported to the laboratory where it would be dried, weighed, ground to a 20-mesh size, and assayed for Sr-90 through digestion and liquid scintillation. Activity could then be reported on a picoCuries per gram (pCi/g) dry weight basis. A rise in the specific activity (pCi/g) over time will indicate penetration and exploration of the sediments' contamination zone.

An increase in the harvested biomass (kilograms [kg] dry matter) with each growing season will mean that the plants have established themselves at the site. Accepted values for successful biomass production will be comparable to those observed at 100-K on an area basis (mT/ha) after two or three growing seasons when the plants will be in the logarithmic phase of growth (PNNL-18294).

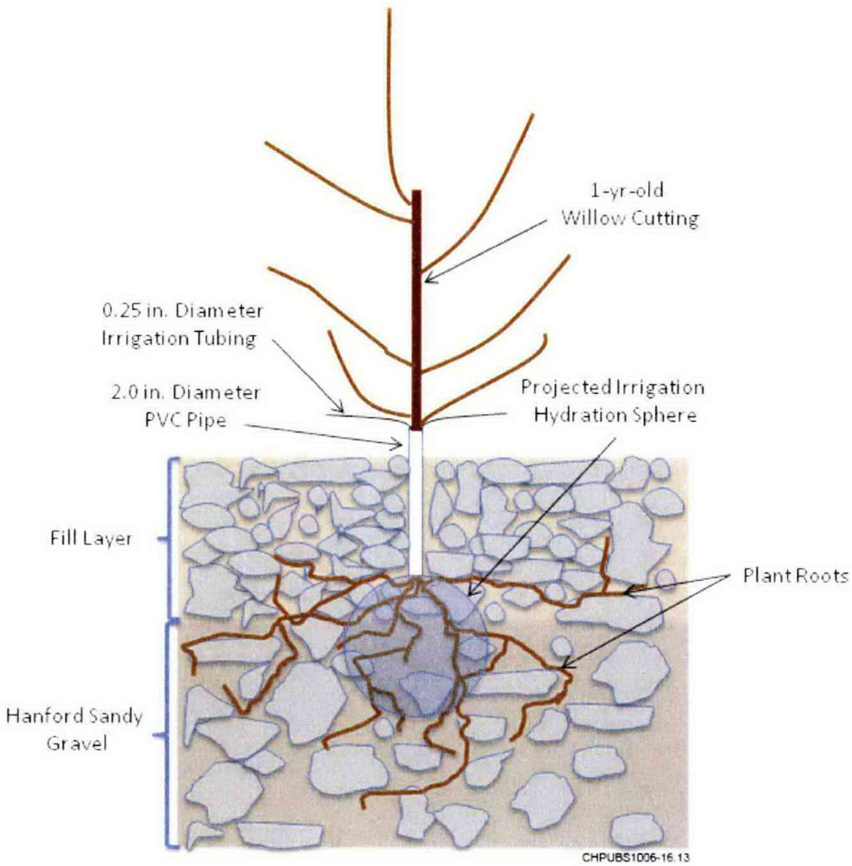


Figure 10. Diagram of Willow Plant After One Year of Growth Showing Movement of Roots Down into the Hanford Layer After Being Directed Downward by the PVC Pipe Around the Plant Stem

3 Treatment Technology Description

This chapter describes the phytoextraction as a treatment technology. It includes descriptions of the mechanisms by which the plants accumulate and partition the contaminant (Sr-90) to permit removal from the site.

3.1 From Phytotechnology to Phytoextraction

Phytotechnology is broadly defined as the use of vegetation to address contaminants in soil, sediment, surface water, and groundwater. Cleanup objectives for phytotechnologies can be contaminant removal and destruction, control and containment, or both. Phytoremediation (i.e., contaminant removal and destruction) is actually a subdivision of phytotechnology.

Phytoremediation is a managed, defined, remediation technique in which living plants or integrated plant/ rhizosphere systems are employed to extract (metals, radionuclides) and/or destroy (organics) soil contaminants, thus reducing the amounts of biologically available soil contaminants to regulatory acceptable levels with minimal soil disturbance/destruction. Plants could stabilize or remove areas contaminated by inorganic/radioactive materials using three mechanisms:

- *Phytoextraction* (Kumar et al., 1995)—where plant roots absorb contaminants into the aboveground plant parts (i.e., leaves, branches, and/or stems)
- *Rhizofiltration* (Dushenkov et al., 1995)—where plants adsorb groundwater or soil pore water contaminants on and into the roots
- *Phytostabilization* (Vangronsveld et al., 1995)—where plant root secretions (e.g., organic acids, natural chelators such as phytosiderophores) (Marschner, 1995) immobilize contaminants in the soil, thereby decreasing soil and wind erosion of contaminants

Phytoextraction is the preferred method to remove the fixed contaminant from the shoreline sediment. Rhizofiltration/phytoextraction combination would assist in removing Sr-90 transiting through the root zone in the groundwater flow. Trees such as willows have been successfully used in the past for phytoextraction of heavy metals (Pulford and Watson, 2002; Klang-Westin and Eriksson, 2003; Meers et al., 2005; Wieshammer et al., 2007).

3.2 Strontium Uptake by Plants

Strontium has no known metabolic function in plants and there is no specific carrier mechanism in the plant root (Marschner, 1995). However, the ratios of Sr concentrations to Ca concentrations in plants do not vary from those seen in the soils, or solutions in which they are growing (Smith, 1971; Andersen, 1973). Further, additions of Ca to soil or hydroponic solutions will depress the uptake of Sr by the plant (Veresoglou, 1995 and 1996). Conversely, elevated Sr levels in hydroponic solutions will decrease the Ca contents of plant tissues (Moyen and Roblin, 2010). Therefore, Sr can share the Ca^{2+} ion channel in the cells of plant roots. These types of carriers are referred to as nonselective cation channels (NSCCs) that allow passive fluxes of cations through plant membranes (Demidchik and Maathius, 2007). Ca^{2+} and Sr^{2+} will rapidly enter the cells of the root (symplasm) and bypass the casparian strip surrounding the vascular tissue (stele) of dicotyledonous plants such as willow (White, 2001). Within the stele, the ions will exit the xylem parenchyma cells and enter the apoplastic space (outside the plasmalemma) to be swept into the xylem and up the stem by the flow of transpirational water (Clarkson, 1991). During the transport from the root to the leaves, some of the Sr may bind to the cells along the path but the majority will reach the leaves. Within the leaf of apple trees, it is thought that the Ca^{2+} tends to flow apoplastically (outside the plasmalemma) from the leaf veins to the epidermal cells and sub-stomatal cavities with the transpiration stream (Yang and Jie, 2005). It may then re-enter the symplasm to participate in the plant's metabolism. The majority of the Sr within the plant cell may be placed onto the cell wall or stored within the vacuoles (Satyanarayana et al., 1999). Neither Ca^{2+} nor Sr^{2+} is very phloem mobile (Marschner, 1995) and so the potential for re-transport out of the tissue in which it resides is low.

Essentially, the terminus for the flow of the SR-90 is in the leaves and, thus, the leaves have a very high percentage of material.

3.3 Coyote Willow

The 100-N area riverbank is dominated by coarse-grained sands, is subjected to significant daily fluctuations in groundwater level (up to 3 m [9 ft]), and is covered with riprap. In this environment, implementation of a phytoextraction strategy requires a plant with roots capable of invading the saturated zone and with an inherent ability to tolerate water-table fluctuations. Such a plant is coyote willow (*Salix exigua*). Coyote willow is a perennial native shrub that grows along the Columbia River throughout the Hanford Site and Mid-Columbia region. As a phreatophyte, the willow's root system readily invades the saturated zone and tolerates prolonged flooding (PNNL-19120). The plant is easily propagated by above ground cuttings, spreads by lateral root suckers (minimizing planting problems), and is amenable to multiple harvests in a given year without the need to replant. In a sand-hydroponic system, the roots of 30 cm (1-ft) cuttings of coyote willow quickly penetrated the sand and exhibited higher density in the saturated zone of the plant containers (PNNL-16714).

Growth chamber studies have confirmed that the coyote willow accumulates Sr and Sr-90 at the same rate that it accumulates Ca from 100-N sediment (PNNL-16714; PNNL-18294). Landeen and Mitchell (1986) investigated Sr-90 uptake by cottonwood (*Populus deltoids*) and the peach-leaf willow (*Salix amygdaloides*) growing around the 216-U-10 Pond. These two species exhibited Concentration Ratios (CR, a measure of a plant's ability to take up [accumulate] Sr in relation to the concentration the root is exposed to in soil porewater within the rhizosphere (the material that is actually available to the root for uptake], defined as [pCi Sr-90/g dry wt. of new growth tissue]/[pCi Sr-90/g soil pore water]) of 63.8 and 85.3, respectively. Coyote willow plants grown in sediment from 100-N consistently averaged CRs of over 70 (PNNL-18294).

When rooted coyote willow cuttings (0.37 m [1-ft] long) were placed into 1 L (0.26 gal) of hydroponic solution amended with Sr-90 at a concentration of 300 pCi/L for 35 days, the plants accumulated 71 ± 4 percent of the total Sr-90 present. Furthermore, within the plant, the majority of the Sr-90 was present in the stem and leaves (Table 1, PNNL-16714; PNNL-18294).

These results with Sr-90 in the laboratory and the field biomass studies mentioned previously (Figure 4) indicate that coyote willow will be a suitable candidate for phytoextraction efforts at the 100-N shoreline.

Table 1. Average Percent of Total Sr-90 Contained in Newly Formed Tissue for Each Plant Segment (Leaves, Stem, and Root)

Plant Segment	Percent of Total Sr-90 in Plant (Avg. ± S.D., N = 6)
Leaves	55.4 ± 10.7
Stem	32.0 ± 13.1
Root	12.6 ± 4.0

Notes:

Plants were grown for 30 days in hydroponic culture with a specific activity of 300 pCi/L of Sr-90.

4 Test Objectives

This Chapter defines the objectives of the treatability study and the intended use of the data. The intended use is to determine if a phytoextraction remediation strategy could be successful at the 100-N shoreline.

As indicated in Chapter 2, the Sr-90 contaminant at 100-N is present both in the sediment currently residing in the riparian zone and in the groundwater currently passing through the same sediment. The high soil and water K_d of Sr-90 ensures that the percentage of contaminant managing to pass through the apatite PRB and into the riparian zone will be very small in comparison to the amount of contaminant already bound to the sediment itself.

The overall goal of this remediation strategy is to use phytoextraction to remove the sediment-bound Sr-90 and groundwater-mobile Sr-90 with minimal disturbance of the bank structure, so that the river and downstream environs will be protected. To achieve the goal, it must be demonstrated that:

- A managed stand of willows can be established on the river's shore
- The plants growing down into the cobble and riprap reach the contaminated sediment near the saturated zone

- When combined with the production of sufficient biomass on a yearly basis, the plant would achieve a removal of Sr-90 from the shoreline at rates greater than 10 to 15 mCi/year

To meet these demands, the objectives of this treatability test are to:

1. Successfully cultivate and manage coyote willows at the shoreline of 100-N, while demonstrating the Sr-90 phytoextraction capability of the willows from both the sediment and transient groundwater
2. Demonstrate that the plants will efficiently remove sufficient contaminant within a given period to meet anticipated regulatory and Tri-Party Agreement requirements
3. Demonstrate that the technology could be safely implemented along the entire 100-N OU shoreline in a culturally sensitive and economic manner

The first objective will show that willows can be placed in selected positions on the shoreline, will survive in place, can reach the contaminant within the sediment profile, and will extract Sr-90 into the shoots for removal from the site. This objective also states that the plant roots will continue to explore the sediment profile over time, increase the rate of extraction as the root mass and biomass production increase, and that the plants can be protected from large and small herbivores to prevent potential offsite transport of Sr-90.

The second objective requires a significant removal of Sr-90 from the resident sediment below the test plants and a reduction of Sr-90 groundwater content over the duration of the test plan life. The plants will be entering the logarithmic phase of their growth cycle after two to three years of onsite growth. Therefore, a plant-by-plant analysis of the contaminant present is necessary to configure the exact quantitative delineation of Sr-90 during the growth cycle of the plants.

Finally, the third objective is to show that all objectives can be met at an acceptable pace while protecting the Columbia River in a culturally sensitive and economically wise manner.

5 Experimental Design

This Chapter describes the methods used when establishing a phytoextraction test site using coyote willows at the shoreline of 100-N. In addition, it discusses the following topics:

- The anticipated activity required for maintenance
- The harvesting procedures necessary to remove the biomass the plants produce
- The means by which the harvested biomass will be analyzed
- The manner in which the resulting data will be analyzed

Also presented are selected decision points when the technique can be evaluated for continuation or termination.

5.1 Site Selection and Description

A location choice for a phytoextraction treatability test requires two things: the presence of sufficient Sr-90 in the sediment to permit a determination of plant efficiency in removing the contaminant, and a physical composition (i.e., sediment, small to large cobble, riprap) reflective of that present across the length of the contaminated shoreline. The portion of the shoreline selected is shown in Figure 11.

This site would extend from just downstream of sampling Well 199-N-146 to about 4.6 m (15 ft) downstream of Well 199-N-122. This is within the well gallery spread chosen for the initial apatite injection study and has a recorded (Well N-122) Sr-90 contamination profile of upwards of 300 pCi Sr-90/g of sediment within 3 m (10 ft) of the road surface. The Sr-90 activity is perched just above the fall 2008 groundwater level (Figure 11). This will promote the roots of the plants to penetrate the contaminated sediment as they pursue the dropping water table through the summer and fall.

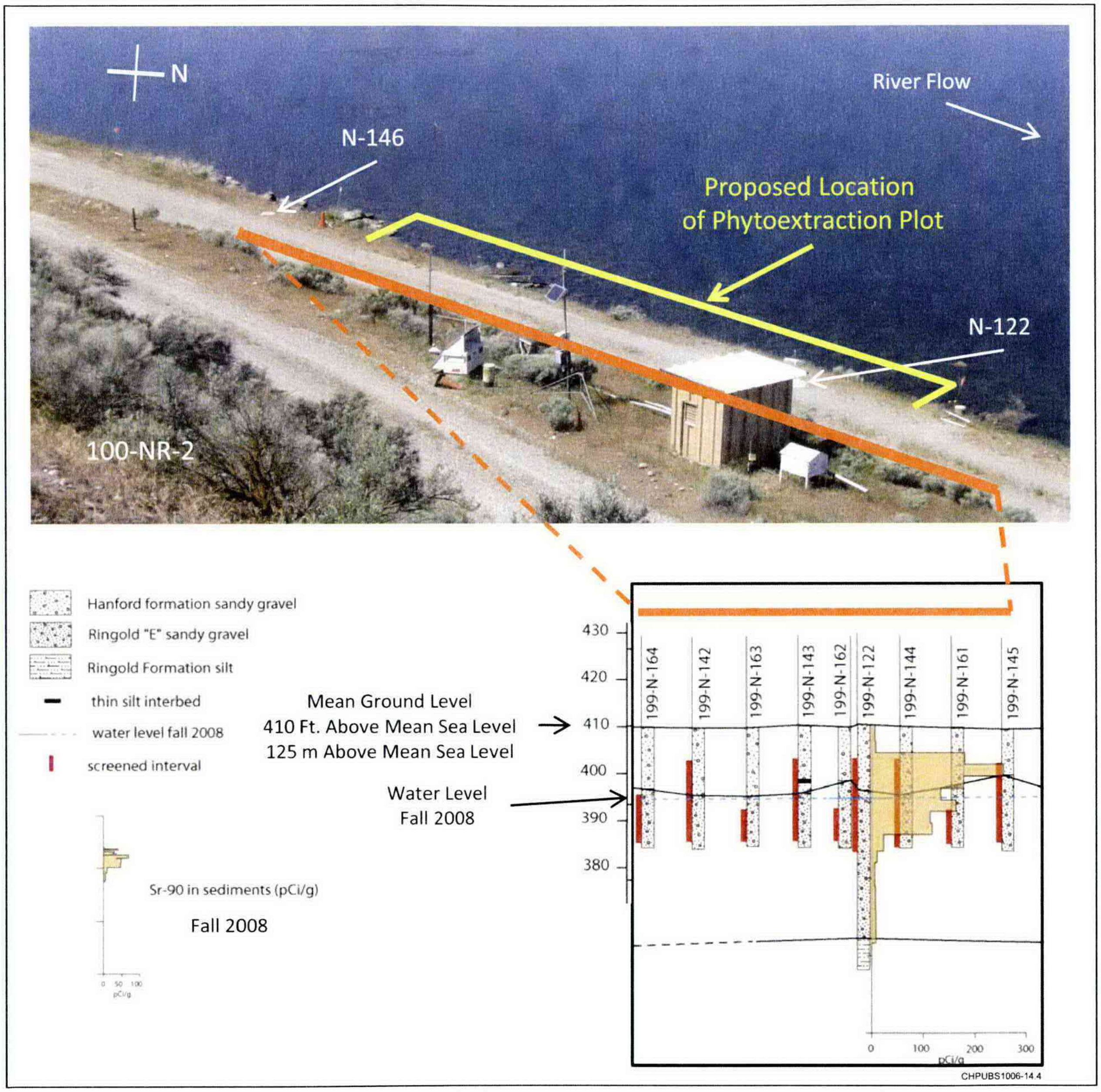


Figure 11. Location of Phytoextraction Treatability Test Plot at 100-N Shoreline

Figure 6 shows that the projected fence line for the site will encompass both the shore cobble and near shore riprap. The picture was taken in May when the river level was elevated from spring runoff. The riprap will be above the late summer/fall river level. This site has a typical shoreline compared to the rest of 100-N.

Figure 12 is a shoreline view at the site showing the formation of the bank down from the roadway. There are two distinct sections to the bank. The first is a steep slope of about 40° that lasts for 3 to 4 m (10 to 12 ft). This is followed by a gradual slope of about 20° that extends out into the river. Both sections have a thick covering of small to large cobble. The projected depth of the cobble/riprap fill is about 1.5 m (5 ft).

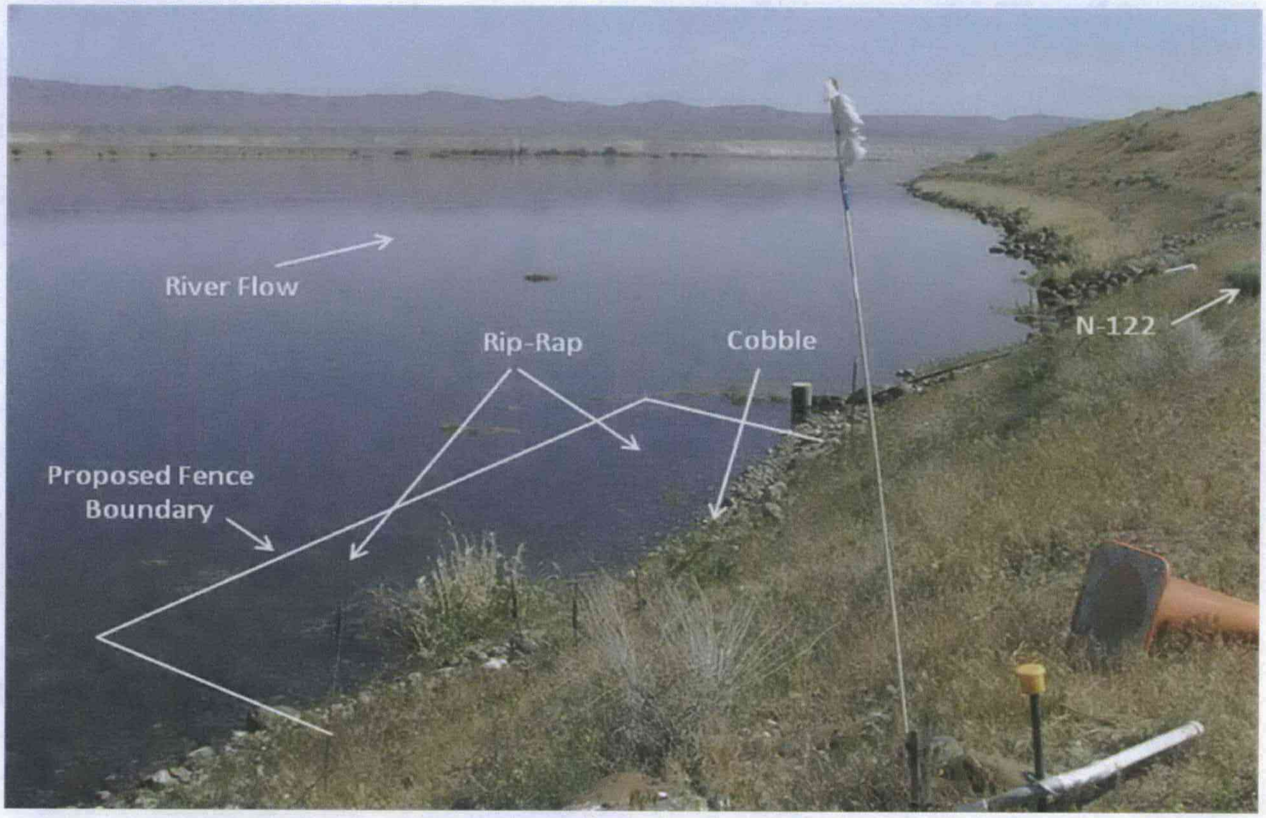


Figure 12. View Upriver Showing the Two Separate Slopes that Compose the Bank

5.2 Phytoextraction Test Site Design

A design for the phytoextraction test site must contain the following elements:

- The type and placement of fencing for preventing herbivore access to the plants
- A means to safely work on the sloping bank and among the large rocks
- A determination of the number and locations for the placement of the plants
- A determination of the location and extent of Sr-90 contamination within the test plot for later confirmation of plant efficiency
- Placement of netting to prevent the intrusion of insectivorous birds preying on insects that might consume Sr-90-contaminated plant material

5.2.1 Exterior Fencing

The 100-N site, similar to the biomass test plot experiment carried out at the 100-K West site, will require a chain-link fence to restrict access of large and small herbivores and unauthorized personnel. The fencing at 100-K was 3 m (10 ft) tall. The fence posts were not driven into the surface but were tethered to cement "ecology blocks" (see Figure 13), which anchored the fence through several flooding situations and high winds.

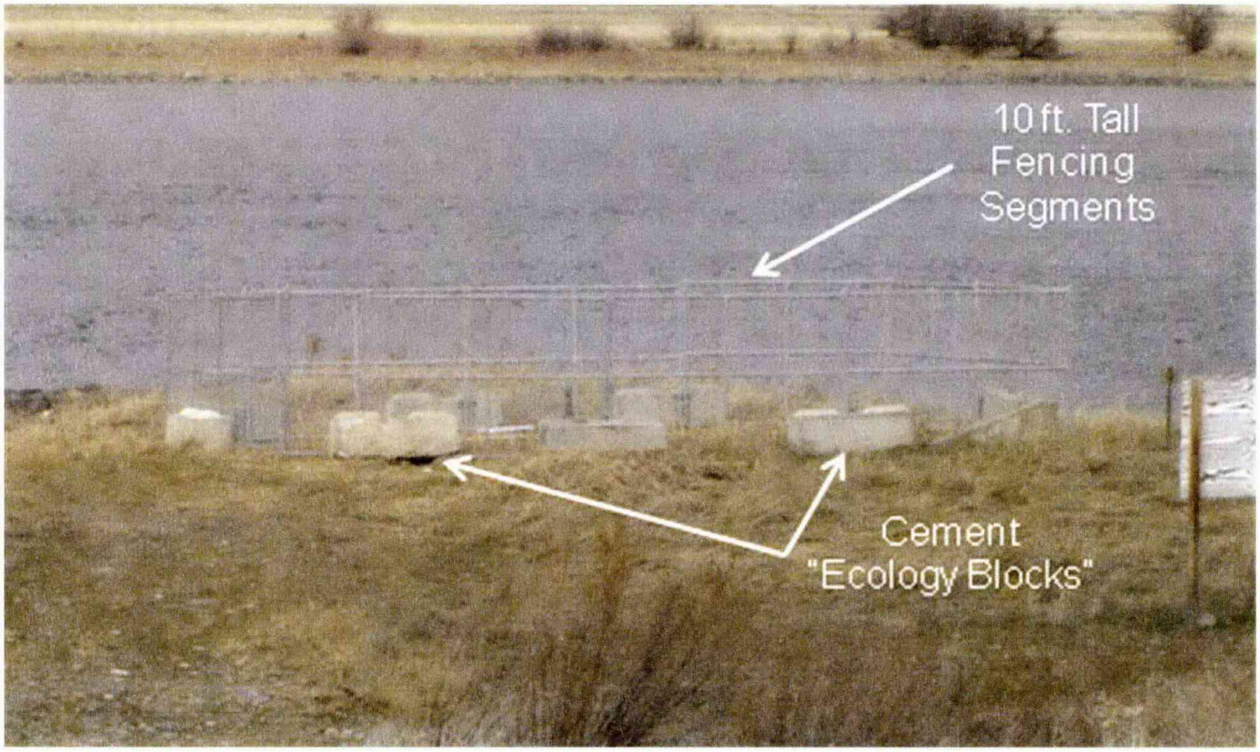


Figure 13. Biomass Test Plot at 100-K West Showing Configuration of Fencing Segments and Anchoring Cement "Ecology Blocks"

The initial step will be a simple removal of all the vegetation currently present in the area between the river and the roadway at selected site. This will be performed under proper radiological controls and the collected biomass managed according to either the *Interim Action Waste Management Plan for the 100-NR-2 Operable Unit*, DOE/RL-2000-41 (WMP) or approved PNNL laboratory protocols.

The fence can then be placed as shown in Figure 14. The fence will be 3 m (10 ft) high and extend to the river's edge at the fall water level, and appropriately placed. Both the cobble and riprap will be contained within its boundary. The estimated size will be 18 × 10 m (60 × 36 ft). There will be two gates located at the roadway level for access to the plot, both to be secured during the test. The fence will be angled down the slope to assure contact with the surface of the cobble around the perimeter. Fence panels will be clamped together, bracing them to "ecology blocks" that will be placed around the external perimeter to stabilize the entire fence.

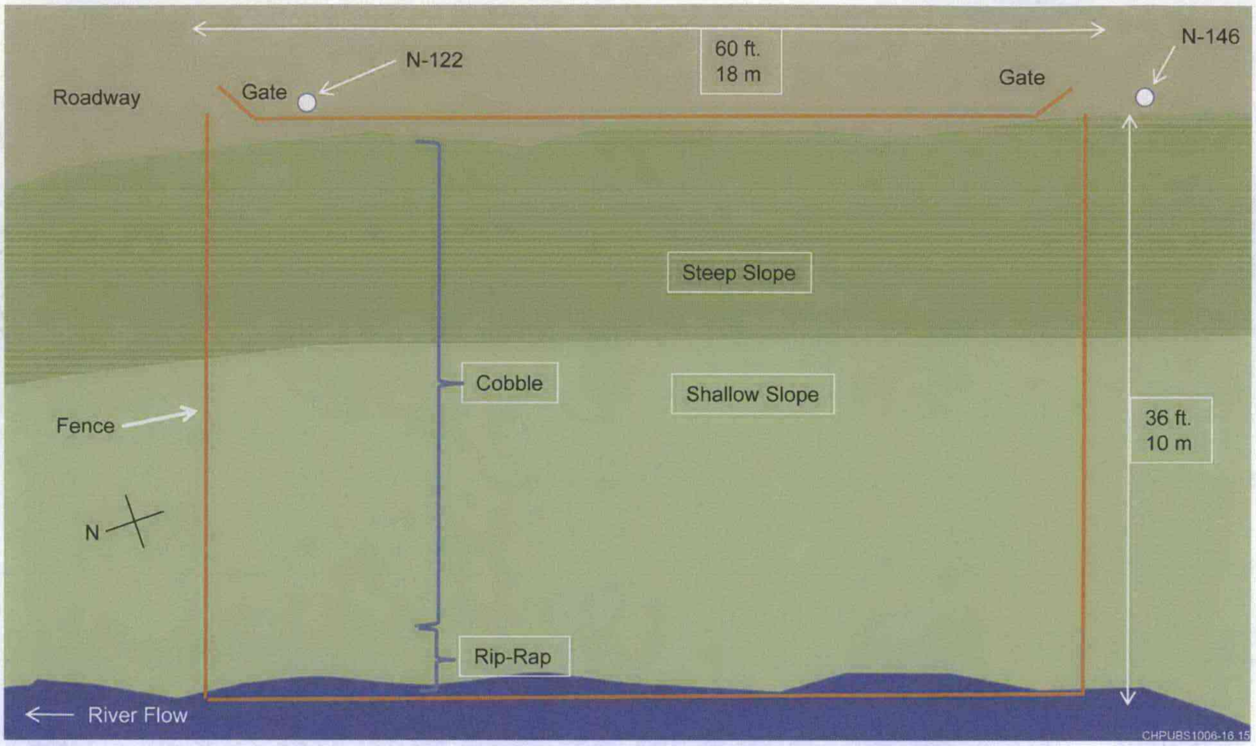


Figure 14. Diagram Showing Fence Placement Around the Phytoextraction Plot at the 100-N Shore

Small animal intrusion will be prevented through the installation of fine (0.75-in. mesh) screening along the base of the chain-link fencing sections. The screening, which will be buried into the cobble, will rise 1 m (3 ft) up the larger chain-link fence to prevent a small animal from crawling up and through the fence. It will be attached to the chain-link with cable ties. This approach was successful in preventing small mammal and snake intrusion into the 100-K West plot (PNNL-19120).

5.2.2 Walkway Placement

Safety for the environment and personnel working at the plot site is paramount to any remediation technology tested. Safe access to the site will require a stabilized platform for climbing the bank and walking the shoreline on a routine basis. Figure 15 A is another river level picture of the plot location showing the large cobble and riprap. A combination of steps and walkways that will be slightly elevated 30 to 40 cm (6 to 8 in.) above the cobble/riprap surface but will permit access to the bank for plant emplacement, routine maintenance, and harvesting procedures could be used. A diagram of such a combination is shown in Figure 15 B. Stairs will descend from the roadway at the steepest part of the slope with walkways (0.8 m [2 ft] minimum width) placed parallel to the river to permit access to the plants.

The stairs and walkways may be either commercially available aluminum, such as those shown in Figure 8, or constructed onsite from pressure treated lumber. The assemblage will be adequately anchored to the ecology blocks to provide stability when the river level rises each spring and for daily traffic over the entire year. The surface of the steps and walkways will be covered with an anti-slip coating for safety. If the river should cover any of the walkways, personnel will not be allowed to traverse the flooded area. The perimeter walkways and steps will have handrails for safety. Additional safety measures may be required.

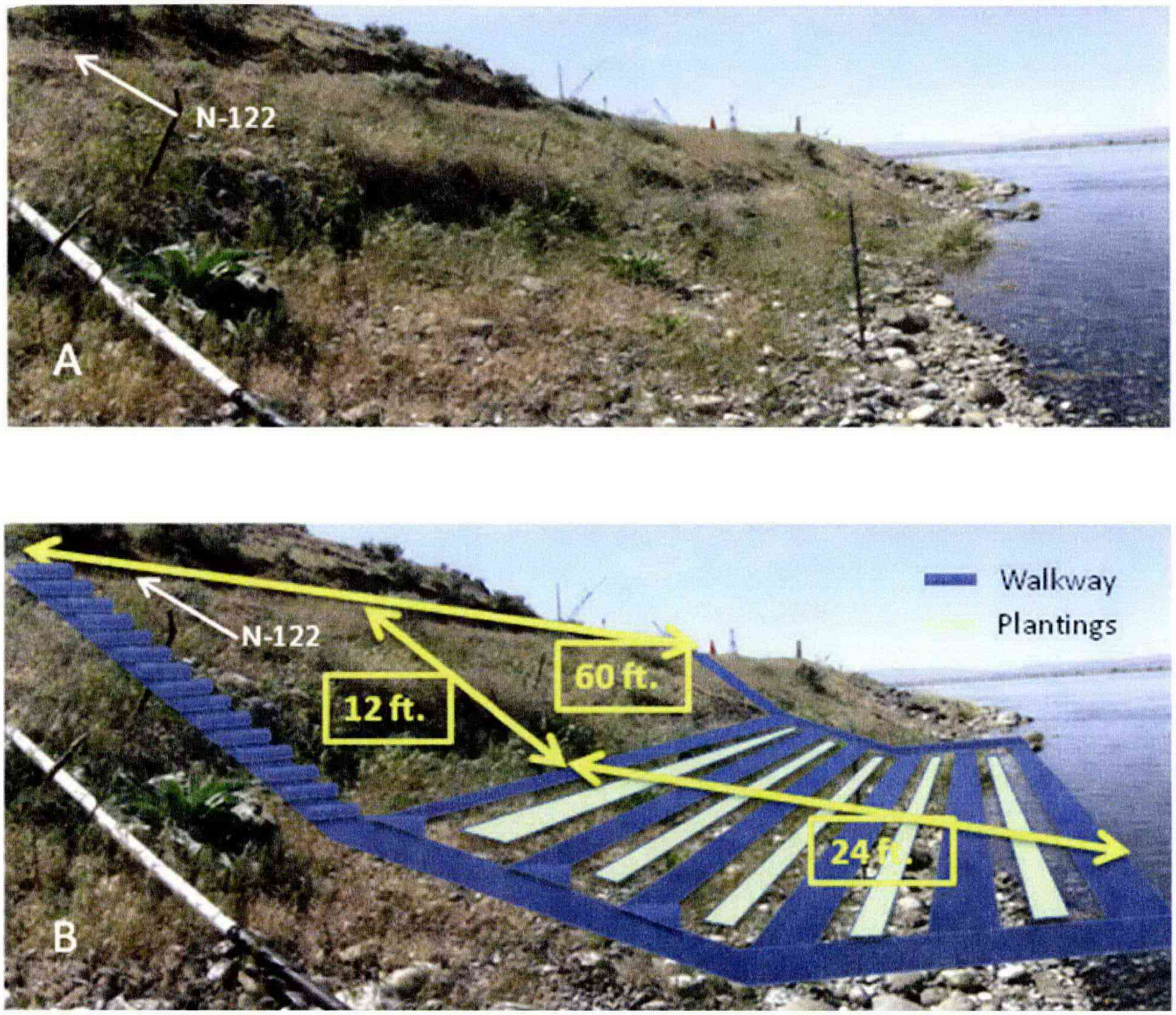
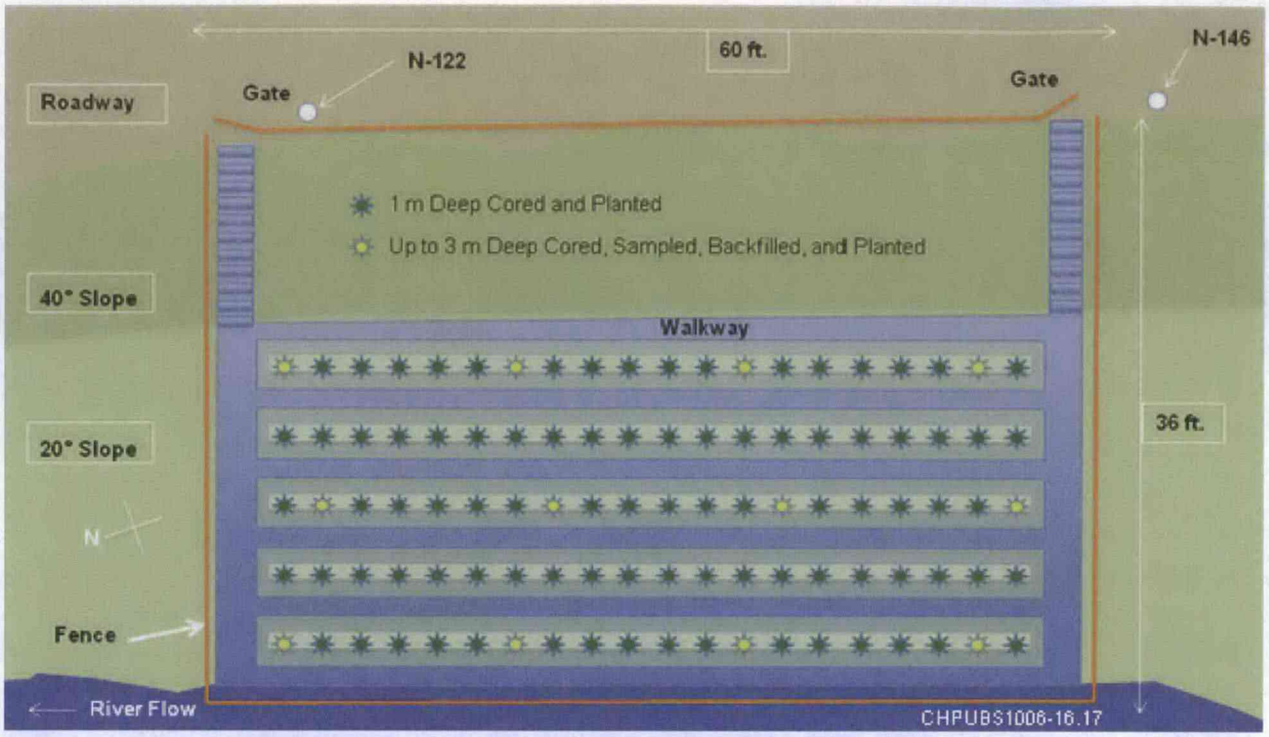


Figure 15. A) River View of Plot Site Showing Slopes of Bank; B) Superimposed Diagram of Steps and Walkways to be Placed at the Site for Personnel Safety and Clear Access to the Plants

5.2.3 Location and Placement of Plants

Coyote willow cuttings were successfully planted and raised for three years at the 100-K plot using 1 m (3-ft) spacing between plants. This permitted rapid spread of the roots with no crowding effects on the plant growth. A similar spacing will be used at the 100-N plot. However, the size of the plot at 100-N will be almost twice the size of previous efforts. Therefore, 100 willow plants will be placed in five rows of 20 plants each starting at the base of the steep slope out toward the river. This distribution is shown in Figure 16.



Note: There would be 100 plants in five rows of 20.

Figure 16. Diagram of 100-N Phytoextraction Plot Showing Plant Placement Within the Boundary Fence

In the Columbia River Basin region, coyote willows are generally planted as cuttings taken from dormant plants during the winter months (December to February). Commercial nurseries primarily sell the cuttings from February to late March for planting. Prior to planting, the cuttings are maintained by placing the proximal end (the end closest to the roots on the stems the cuttings were taken from) into water and keeping the plants below 4°C. As the temperature rises in the spring, gravity and moisture will prompt formation of root initials from meristems located in the vascular tissue (cambium) present just below the bark. At this time, the cutting can simply be driven into the soil and considered planted (Figure 17). The roots will develop and leaf/shoot initials will form from meristematic tissue located just below the previous year's leaf scars on the upper (distal) portion of the cutting.

Previously rooted plants can be placed into the soil at other times of the year with some success but it is better to wait until after leaf drop in the fall when the temperatures begin to moderate. There is currently a supply of 0.9 to 1.2 m (3- to 4-ft) long, (1 to 2 cm [0.75- to 1-in.] diameter) coyote willow cuttings (2010 stock) planted into non-contaminated Burbank soil (taken from the 200 Area alongside the Yakima Barricade) growing in the PNNL greenhouse (Figure 18). These could be planted at the 100-N plot as early as fall 2010.

The late fall planting of already rooted cuttings will require a modification of the traditional planting method. These plants will have an established root system that will need to be protected during the insertion into the sediment. A three-year-old plant grown from cuttings is shown in Figure 19. The shoots that emerged at the apical end of the plant have been removed but note that a number of shoots are emerging from the stem at the soil surface level. This is typical of these plants. Also, note that the roots emerging from the sub-soil portion appear to go laterally for some distance prior to turning downward.

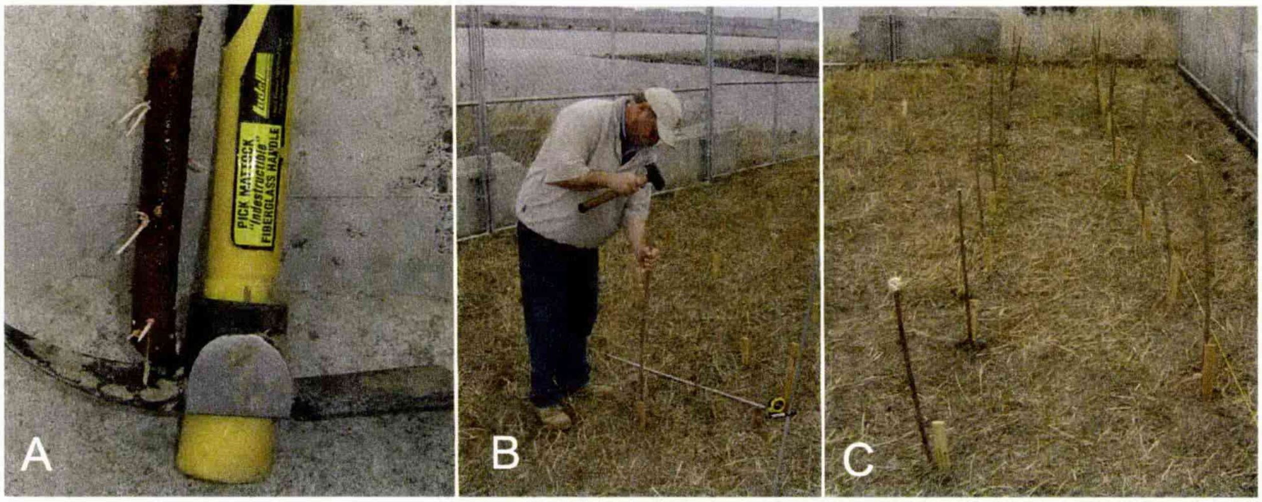


Figure 17. Pictures from the 100-K West Test Plot Installation Showing: A) Root Initials Emerging from Lower Portion of Coyote Willow Cutting; B) Method Used to Plant the Cuttings; and C) Planted Cuttings

Figure 18. Coyote Willow Cuttings from 2010 Crop Growing in the PNNL Greenhouse (June 2010)

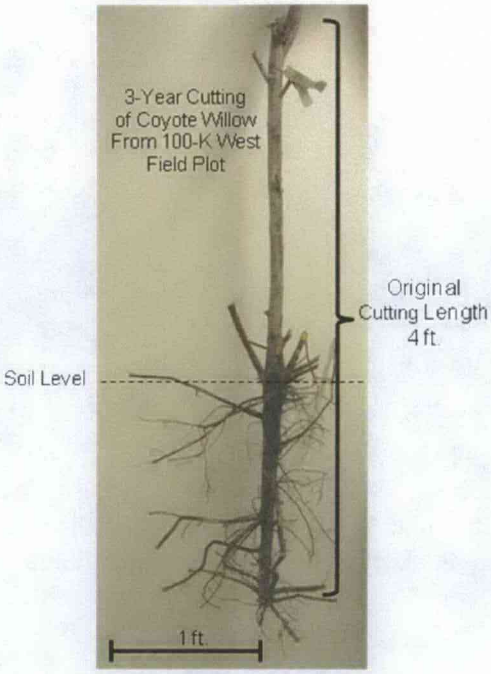


Figure 19. Coyote Willow Cutting Grown for Three Years at the 100-K West Plot Showing Patterns of Shoot and Root Development

It will be important from the outset of the test to prevent or limit lateral distribution of roots. These roots will grow to reach the contaminated strata but at a slower rate than those initially growing in the downward direction. Plants grown in the PNNL greenhouse will be used for the initial planting at 100-N. These will be removed from their pots following leaf drop in the fall when the plant is entering dormancy and plant transpiration is greatly reduced. The potting soil (Burbank) will then be washed off the roots.

A 5 cm (2-in.) diameter and 1 m (3-ft) long PVC pipe will be prepared to receive the plant. The pipes are necessary so the plants can reach above the riprap. The pipe will be scored on two opposing sides to facilitate breakage as the plant matures and expands in diameter (Figure 20 A). In addition, two quarter-inch-diameter irrigation tubes will have been glued to the inside of the pipe over its length (Figure 20 A). The plant roots will then be threaded into the pipe to the point that 20 to 30 cm (8 to 12 in.) of the lower stem will rest inside the pipe. Wet soil and water will then be sluiced into the pipe to fill in all the space around the roots to prevent air gaps and subsequent root dehydration. The pipe/plant combinations will then be stored upright in water at 4°C until the site preparation is completed.

Holes 0.8 to 1.0 m (30- to 39-in.) deep and 5 to 7.5 cm (3- to 5-in.) diameter will be drilled into the cobble and substrate using a Geoprobe® or similar device at 1 m (3-ft) intervals at the 100-N plot as shown in Figure 16. The drilling will be conducted by CHPRC, in accordance with CHPRC or subcontractor procedures. If appropriate, or required, radiological surveys will be performed during drilling operations. PNNL personnel will then place the pipe/plant combinations into the drilled hole, ensuring contact with the bottom of the drilled hole. This will prevent an air gap and possible desiccation of the roots as they emerge from the pipe in the spring.

The function of the pipe will be to force the roots initially in a downward direction through the cobble fill toward the contaminated sediment. Additionally, placing them almost three feet into the fill profile will mean that the roots will have traversed over halfway through the fill layer from the start.

Water levels at the site will be constantly monitored to ensure that the plants will not be stressed. The irrigation lines will provide water to the area just below the pipe during the period following planting and in the early spring (October to November and February to April) when the river level is low and the sediment will be dry. The hydration sphere (Figure 20 B) will also help to orient the roots to the contaminated horizon.

Irrigation water will be taken from the Columbia River at the site. Anticipated volumes are less than 380 L (100 gal) per day. Water will be pumped through a drip irrigation system from a direct current pump powered by a solar panel placed within the compound. The pump will run on a timer.

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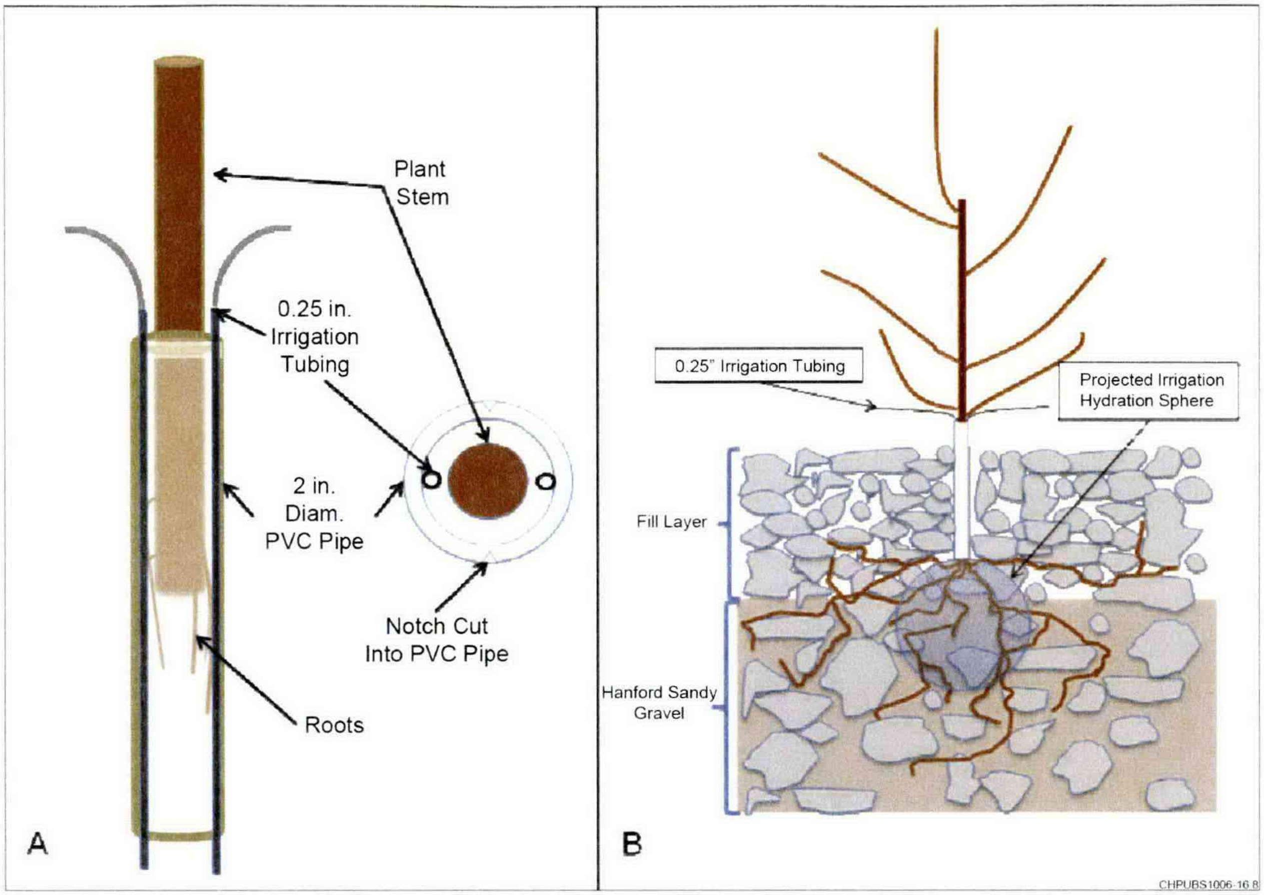


Figure 20. Diagrams Showing (A) The Composition of a PVC Pipe/Plant Planting System and (B) Projected Placement of the System Within the Bank Profile at 100-N

5.2.4 Determination of Sr-90 Contaminant Location and Extent Within Plot

Previous estimates of sediment contaminant distribution at the 100-N shoreline (Figure 11) were taken from wells driven into the roadway above the proposed test plot. Determining the effectiveness of the phytoextraction technology will require more detailed knowledge of the actual extent of contamination in the proposed plot area itself. A three-dimensional map of Sr-90 distribution, coupled with the actual extracted Sr-90 contained in the harvested plant dry matter, could indicate the extent of root penetration and efficiency of contaminant removal over time.

Sampling cores will be taken within the planting rows at 5 m (16-ft) intervals. Using a Geoprobe or similar device, the cores will be 3 m (9.8 ft) deep and 2.5 to 5 cm (1 to 2 in.) in diameter.

These cores will be used to map the location and extent of Sr-90 contamination in three dimensions within the test plot site. Proposed locations for these sediment samples are shown in Figure 21.

The drilling activities will be conducted by, or under the direction of, CHPRC and in accordance with CHPRC or subcontractor procedures. The quality requirements for sampling activities, including chain-of-custody, storage, and records requirements will be specified in the work plan or test plan. Upon removal of the cores, the retrieved sediment will be separated into 1 m (3-ft) segments and placed into containers for transport to PNNL following approved radiological protocols and radiological work permits (RWPs).

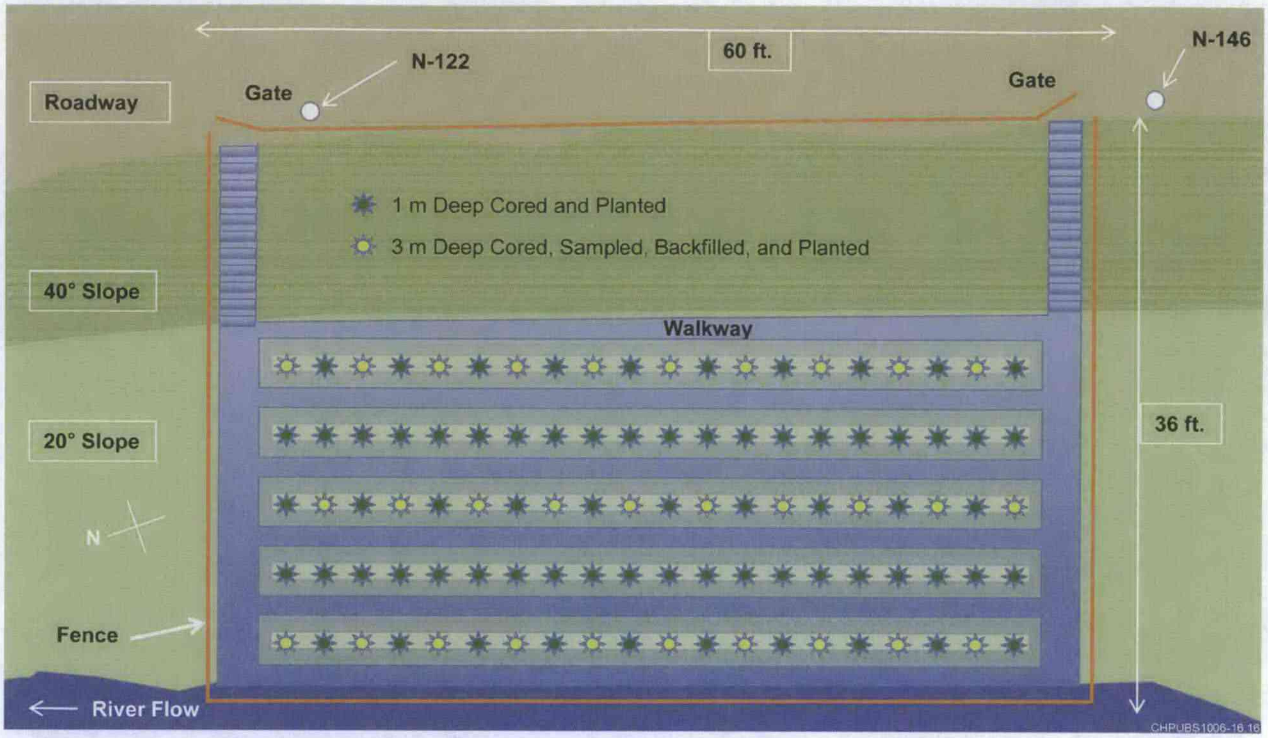


Figure 21. Diagram Showing Locations of 3 m (9.8-ft) Deep-Cored Samples Within the Planting Grid

Sample receipt, handling, and storage activities will be conducted in accordance with *The Columbia River Protection Supplemental Technologies Quality Assurance Project Plan* (PNNL-16340). Chain-of-custody for samples will be documented using a chain-of-custody form. Each PNNL facility is a secured area, restricted to authorized personnel only. Chain-of-custody will be documented for moving samples from one facility to another, but not for moving samples within a secured facility. Documentation of unique sample and subsample identifications will be maintained for samples received. The documentation may consist of entries in laboratory record books or data sheets.

Upon removal of the cores, the holes will be backfilled to a depth of 1 m (3 ft) with non-contaminated Hanford sediment and PNNL personnel will place the plant/PVC pipe into the remaining space. Care will be taken to prevent air gaps between the sediment and the pipe/plant combination.

The sediment coring samples will be analyzed for Sr-90 content (ion-exchangeable and total Sr-90) at PNNL using the techniques described in previous reports (PNNL-16891; PNNL-19524). Data will be expressed as pCi Sr-90/g dry weight of sediment and will be presented as lateral and depth distribution within the plot.

5.2.5 Routine Plant Maintenance

PNNL personnel will perform primary maintenance at the site following installation and planting, which will consist of weeding, upkeep of the irrigation system, periodic fertilization, and general policing of possible plant detritus during the growing season. Collected plant material, either weeds or detritus from the willows, will be managed as waste in accordance with *Interim Action Waste Management Plan for the 100-NR-2 Operable Unit* (DOE/RL-2000-41). It will be kept in a closed and locked container secured within the fence until moved out to a waste collection site. These activities and harvesting activities described below will be coordinated with Radiation Control and carried out under approved radiological controls.

As done at the 100-K site, fertilizer stakes will be placed 15 cm (6 in.) deep at 2 m (6-ft) intervals along the rows. Care will be taken to keep the stakes at least 0.5 m (1.5 ft) away from any of the plantings to prevent fertilizer toxicity ("burn"). Scheduled fertilizations may be performed at four-month intervals during the growing season.

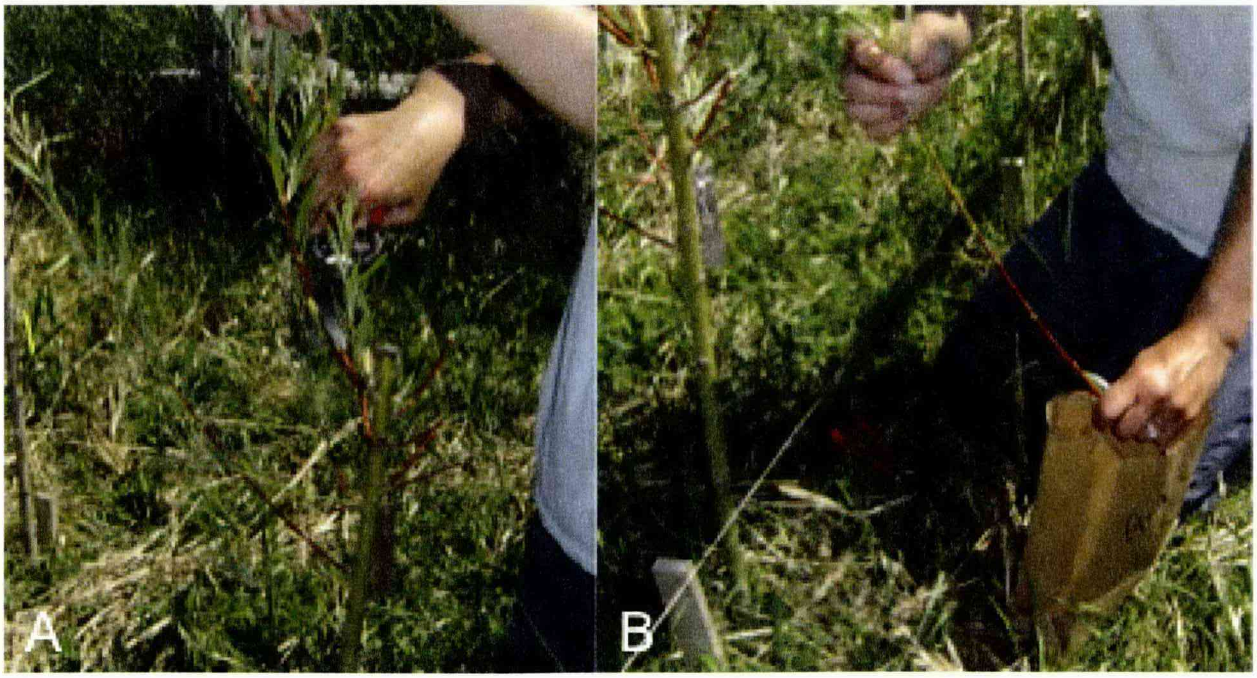
These tasks and site upkeep will require the placement of a locked storage trailer, or container next to the plot on the shore roadway to contain frequently used tools and equipment.

5.2.6 Plant Harvesting Strategies and Sample Analysis Procedures

Efforts will be made throughout the study to select only tissue, stems, and leaves that have emerged and developed from the time of the initial planting or previous harvest. Two nodes (leaf scars on the stems) will be left on the emerged branches to provide starting points for the next season's growth. Although demonstrating expansion in girth and certainly root development, the original cuttings will be undisturbed until the end of the study and will not be part of the reported biomass yield and activity.

Harvesting will occur in the fall by PNNL personnel. An exact date cannot be determined as the maturity (senescence status) of the plant depends on environmental factors such as water status, temperature, and sunlight. Harvesting will then be done when 10 to 20 percent of the leaves begin chlorophyll degradation (yellowing). The harvesting procedure will be to remove new growth stems from the main trunk, strip the leaves into a pre-tared paper bag, and then cut the stem into 10 cm (2-in.) sections and place into another pre-tared paper bag (Figure 22). Bags will be labeled, stapled shut, placed into a plastic bag, radiologically surveyed, and taken to the PNNL laboratory where they will be resurveyed into a radiologically controlled area and unpacked. A fresh weight will be taken and the tissues will be dried at 80°C for 48 to 72 hours, and then a final dry weight taken. The tissues will then be ground to 20-mesh size in a Wiley Mill® and stored in glass jars at room temperature in a radiologically controlled area.

Figure 22. Harvesting of Coyote Willows: (A) Removing Stems and (B) Stripping Leaves



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Aliquots of the ground leaf and stem tissue (0.25 to 0.5 g depending on sample size) will be placed in 20-mL (0.7 oz) scintillation vials, wetted with 1 mL (0.03 oz) of 8 N HNO_3 (Optima Grade), and ashed at 500°C overnight in a muffle furnace. The ash will be re-suspended in 2 mL (0.07 oz) of concentrated HNO_3 (Optima Grade), dried overnight at 100°C, and ashed again at 500°C for 12 hours. One mL of 0.01 N HNO_3 will then be added to the ash along with 15 mL (0.5 oz) of Ready-Safe™ scintillation cocktail. The sampling and ashing will be performed in triplicate for each sample. The furnace expected to be used to ash the samples will accommodate 24 samples for each run. Included in each extraction will be blanks and spiked samples of non-contaminated plant tissue. All samples will be counted with a Beckman LS6500 (Beckman Coulter) scintillation counter with appropriate quench curves and standards. The instrument will be calibrated each day with certified tritium standards. The data will be corrected for Yttrium-90 (a daughter product of Sr-90 decay) interaction and expressed as pCi/g dry weight. Remaining unused dried/ground plant samples will be stored in a radiologically controlled area until being managed according to the WMP (DOE/RL-2000-41) and the approved PNNL laboratory protocols.

5.2.7 Bird Intrusion Protection

During the growing season, the plants within the plot will be available for herbivorous insect predation since the fencing will not be able to prevent their access to the plants. It has already been determined that insect predators such as aphids and moths will not present a problem with offsite transport or biomagnifications of Sr-90 contaminant (PNNL-18294). The potential exists, however, that insectivorous birds may enter the plot, feed on sufficient insects containing some contaminated plant tissue in their digestive system, and carry some of this material out of the plot when they leave. While no significant herbivorous insect activity was seen at 100-K over the three study years, such interaction could not be discounted in the field. Therefore, bird access to the plots will be controlled during those times when such insects may be present (i.e., the growing season) using bird netting (3.5 cm [1-in.] square nylon mesh) placed over the top of the perimeter fencing.

To this end, twelve 3.7 m (12-ft) long treated wood, 20 × 20 cm (4- × 4-in.) posts will be fastened to the perimeter fence at ~4 m (~12-ft) intervals down the slope sides, four to each side, and across the top and bottom (Figure 23). Within the planting area, four additional posts will be placed and braced to the walkways (Figure 24). These will be support poles for netting to be placed over the compound to prevent bird intrusion onto the trees during the growing period of February to October.

5.2.8 Decision Points

Once initiated, the phytoextraction test deployment at 100-N will take up to three years to completely demonstrate that sufficient biomass containing significant amounts of Sr-90 will be produced by coyote willows. Prior to completion of this study, the 100-NR-2 OU Remedial Investigation and Feasibility Study (RI/FS) Report will require input for the development of a proposed plan to either continue the study or terminate activity.

The only available standard by which the success of the technology can be evaluated is the biomass field study conducted at the 100-K West experimental plot. While that study showed significant increases in biomass production in the third year of the study, marked increases were present at the completion of the second growth season (PNNL-19120).

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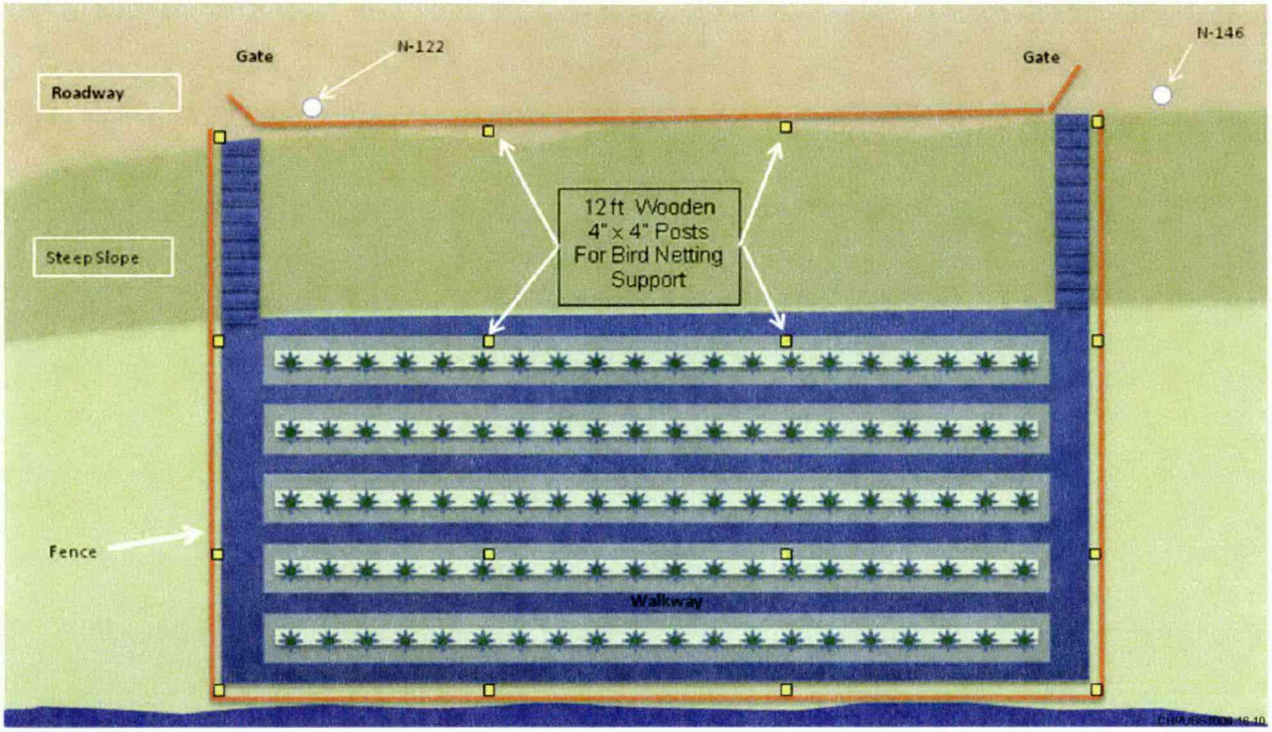


Figure 23. Diagram Showing Positioning of Wooden Posts Within Plot Used to Support Bird Netting

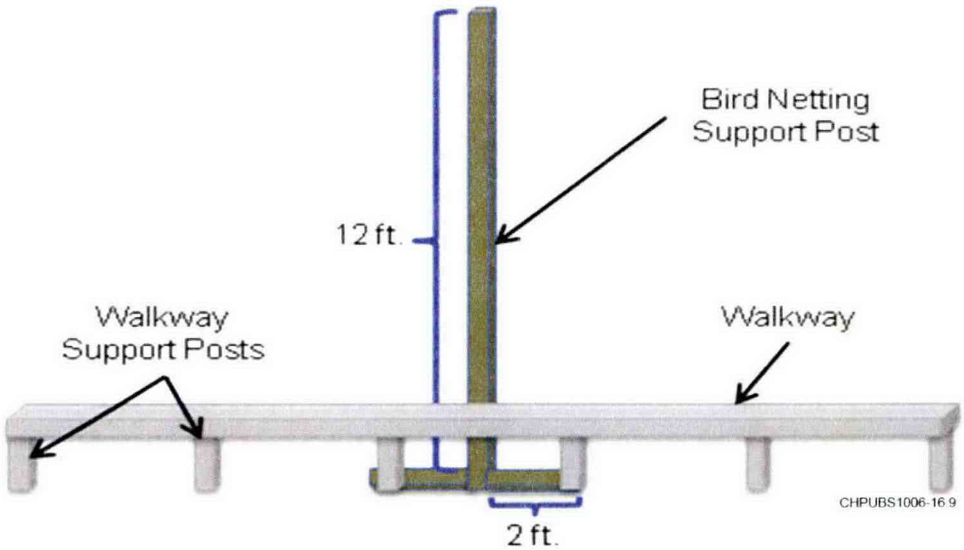


Figure 24. Diagram of Wooden Posts Used to Support Bird Netting Within the Plot and Attached to the Walkways

The initial decision point will be at the conclusion of the first full growing season and will require:

- Safe construction of the plot with emplacement and survival of the plants
- Analysis of the soil cores taken below the plants

- Presence of Sr-90 in the plant tissues showing that the plant rooting system can grow down into the contaminated sediment layer

The completion and successful meeting of these requirements at the end of the first growing season could serve as an initial decision point for continuation of the study.

The second decision point will be after the completion of the second growing season and will require:

- Continued survival of the plants with increased biomass accumulation comparable to the previous study on a dry-matter kg/ha (lb/ac) basis
- Marked increase in the specific activity (pCi Sr-90/g dry weight) of the tissues (stem and leaves)
- Continued worker and environmental safety

The completion and successful meeting of these requirements at the end of the second growing season would likely serve as a decision point for continuation of the study.

The third and final decision point will be at the completion of the third growing season and will require:

- Continued survival of the plants with a significant increase in biomass accumulation comparable to the previous study on a dry-matter kg/ha (lb/ac) basis showing that the plants are entering the exponential phase of their growth
- Continued increase in the tissue specific activity with a goal of greater than 300 pCi/g dry weight, demonstrating ongoing exploration and penetration of the contaminated sediment by the plant roots
- A demonstration that the work involved in the conduct of the study can be done safely and that the environment outside of the plot will also remain safe (i.e., no inadvertent offsite transport of the contaminant)

These final requirements, in conjunction with those from the two previous years, could support a final determination. In addition, they could determine whether the technology should be continued and expanded to the rest of the shoreline or terminated and the bank restored to its previous condition.

5.2.9 Project Termination—Cleanup and Restoration

If a decision is made to terminate the study at any time, the following will occur at the field site:

- The plants will be cut down to 15 cm (6 in.) above ground level. Those tissues collected will be managed according to the WMP (DOE/RL-2000-41) and under approved radiological controls.
- A 6 mm (0.25-in.) hole will be drilled into the cut stem to a depth of 8 cm (3 in.), the hole filled with an approved herbicide (likely Rodeo® herbicide), and sealed with mastic. The plant will remain in place for three weeks to allow the herbicide to kill the roots, and then the remaining above ground portion will be removed and managed according to the WMP (DOE/RL-2000-41). Any roots remaining within the soil that may contain Sr-90 would retain less than 10 to 15 percent of the total Sr-90 contained in the plant at the time of removal, and will not add to the total Sr-90 inventory presently in the riverbank.

® Rodeo is a registered trademark of Dow Agrosciences, Indianapolis, Indiana.

- The site will be dismantled and the material used to construct the stairs and walkways managed according to the WMP (DOE/RL-2000-41) and under approved radiological controls. If cleared by the radiological control organization, stairs, walkways, fencing, ecology blocks, and other such reusable items will be removed and recycled to other cleanup activities onsite. Small animal screening will be managed according to the WMP (DOE/RL-2000-41), since part of the material was located below the bank surface.
- Any unused fertilizer will be properly disposed if it cannot be recycled to other activities onsite.

At the PNNL laboratory, the following will occur:

- All stored radioactive plant material or plant material in the analysis process will be disposed of following approved PNNL laboratory protocols.
- Chemical wastes such as acid solutions or liquid scintillation vials filled with cocktail will be processed and disposed of following approved PNNL laboratory protocols.
- Unused chemicals will be recycled.
- Laboratory record books, data files, and all related paperwork will be boxed and sent to records storage.
- All project closeout requirements will be followed.

6 Equipment and Materials

Table 2 lists the minimum anticipated equipment and materials needs for the initiation, maintenance, and cleanup of the phytoextraction technology test.

Table 2. Equipment, Materials, and Chemical Needs for the Phytoextraction Test Activity at the 100-N Site, PNNL Laboratory, and Greenhouse

Location	Activity	Equipment/Material
100-N Shore	Site Construction	Chain-link fencing
		Small diameter metal screening
		Concrete ecology blocks
		Treated lumber or aluminum step/portable walkway material
		Treated lumber for bird netting support
		Bird netting
		Pneumatic drill
		Coyote willows
		5 cm (2-in.) diameter schedule 40 PVC tubing
		0.6 cm (0.25-in.) diameter irrigation tubing
		DC water pump with filter and flow controls
		Solar panels to power DC pumps
		Timers
		Electrical connections to AC power located within 9 m (30 ft) of the test site
		Solar powered weather station with data loggers
		Lockable storage unit for tools, RWP clothing, and waste bags
		Lockable storage unit inside plot for radioactive waste

Table 2. Equipment, Materials, and Chemical Needs for the Phytoextraction Test Activity at the 100-N Site, PNNL Laboratory, and Greenhouse

Location	Activity	Equipment/Material
	Site maintenance	Garden tools for weed removal Fertilizer spikes Expendables including waste bags, irrigation repair supplies
	Harvesting	Pruning tools Sample bags Markers
	Site closure	ERDF waste containers Herbicide (Rodeo)
PNNL Laboratory	Sample analysis/ storage	Analytical balances Drying oven Wiley Mill and accessories HEPA filtered vacuum cleaner Liquid dispensers/pipettes Muffle furnace Stirrers Sonicating bath Liquid scintillation spectrometer Expendables—absorbent paper, printer paper, towels, gloves, tape, markers, scintillation vials, glass storage jars, laboratory glassware, water filters and purification columns, liquid scintillation cocktail, analytical grade or higher acids, radioactive waste bags
PNNL Greenhouse	Plant preparation	Plastic pots Non-contaminated Hanford soil Fertilizer Garden tools

DC = direct current
AC = alternating current
ERDF = Environmental Restoration Disposal Facility
HEPA = high-efficiency particulate air (filter)

7 Sampling and Analysis

Sampling and analysis procedures for the phytoextraction field test have been described in Section 5.2.4. Details of the sampling and analysis are provided in Appendix A. Plant tissue samples (stems and leaves) will be collected from the coyote willow trees just prior to leaf drop in the fall. This may occur in fall, based upon current weather conditions. The plant material will be properly transported to the PNNL laboratory. There, the material will be handled and analyzed in radiologically controlled areas under approved radiological controls. Samples will be weighed, dried, and weighed again. Aliquots will be taken (minimum of three for each tree [leaves and stems]) and processed under PNNL Chemical Process Permit No. RTL520-314-CPP-9618 *Process for Acid (HCl or HNO_3) Digestion of Plant Tissue*. Following digestion, a liquid scintillation cocktail will be added to the ashed samples and the samples counted with a liquid scintillation spectrometer using appropriate calibration, standards, blanks, and spiked samples. Data will be corrected for Y-90 counts.

8 Data Management

All operational, monitoring, and field data will be recorded manually on data sheets. The original data sheets will be pasted into a bound field notebook soon following the test. Data from analytical activities conducted at PNNL for Sr-90 determination and biomass assessment will be recorded in PNNL Laboratory Record Books.

9 Data Analysis and Interpretation

The data presented will be both of a qualitative and quantitative nature. Qualitative data will include progress in the site construction, site condition over time, and site responses to environmental changes (e.g., spring flooding) and plot removal/environmental restoration. These will generally be presented in a pictorial fashion.

Quantitative data will include measurements on individual plants (i.e., survivability, height, apparent insect damage, biomass production, total plant and organ [leaves, stems] Sr-90 accumulation and Sr-90 specific activities). Quantitative data for the entire plot will include total biomass production expressed both on a plot and fixed-area (kg/ha [lb/ac]) basis, total Sr-90 accumulation also expressed on a plot and fixed-area basis (mCi/ha). These data will be presented as tables and graphs. The entire plot quantitative analysis will include positional effects (i.e., appearance of stress symptoms, survivability, and growth rate) for the plants, expressed as tables and graphs.

Interpretation will relate to the effectiveness of the technology within the trial plot and the technology's suitability for application across the 100-N shoreline.

10 Health and Safety

All work performed onsite will be conducted in accordance with a site-specific treatability study Health and Safety Plan and any applicable task specific job safety analysis. The Health and Safety Plan will address radiological concerns. Gloves and eye protection are needed while handling chemicals and during sample collection. Sample media, waste, and detritus will be kept in separate bags for periodic Radiological Control Technician survey/release. As described in Chapter 5, special provisions will be made for safe access to the steep slopes that characterize the site at the 100-N shoreline.

11 Waste Management

All regulated waste generated from this TTP, including but not limited to samples, vegetation, soil, insects, and other materials, will be managed in accordance with the *Interim Action Waste Management Plan* for the 100-NR-2 Waste Operable Unit, DOE/RL-2000-41 (WMP) or approved PNNL laboratory protocols. Unused samples and associated laboratory waste for sample analysis will be dispositioned in accordance with the laboratory contract and agreements for return to the project site. Pursuant to 40 CFR 300.440, "Procedures for Planning and Implementing Off-Site Response Actions," DOE-RL Project Manager approval is required before returning unused samples or waste from offsite laboratories (as applicable).

12 Reports

At the conclusion of each growing season, an annual letter report will produced. A final formal report will be produced either after the third growing season or at the termination of the project, whichever comes first.

13 Environmental and Regulatory Compliance

Laws and regulations pertaining to the response actions are identified through the Applicable or Relevant and Appropriate Requirement (ARAR) identification process. The ARARs identification process is based on CERCLA guidance (EPA/540/G-89/004, EPA/540/G-89/006, and EPA/540/G-89/009). CERCLA Section 121 requires, in part, that any applicable or relevant and appropriate standard, requirement, criterion, or limitation under any federal environmental law, or any more stringent state requirement pursuant to a state environmental statute, be met (or a waiver justified) for any hazardous substance, pollutant, or contaminant that will remain onsite after completion of remedial action.

This Treatability Test Plan is conducted under the Interim Remedial Action Record of Decision for the 100-NR-1 and 100-NR-2 Operable Units (EPA/ROD/R10-99/112), which discusses ARARs. The selected interim remedial actions for the 100-NR-2 OU that will be conducted under this TTP are protective of human health and the environment, comply with ARARs, and are cost effective.

Under DOE Order 451.1B, *National Environmental Policy Act Compliance Program*, Section 5.a.(13), DOE will "...incorporate NEPA values, such as analysis of cumulative, offsite, ecological, and socioeconomic impacts, to the extent practicable, in DOE documents prepared under the Comprehensive Environmental Response, Compensation, and Liability Act." These NEPA values include, but are not limited to, cumulative, ecological, cultural, historical, and socioeconomic impacts, and irreversible and irretrievable commitments of resources. This treatability test occurs in a previously disturbed area at 100-N, and as such does not have the potential to impact NEPA values. A general discussion of NEPA values anticipated to be addressed for the 100 Area can be found in the *100 Area Integrated RI/FS Work Plan* (DOE/RL-2008-46, Rev. 0). The complete analysis will be provided in the future feasibility study.

14 Schedule

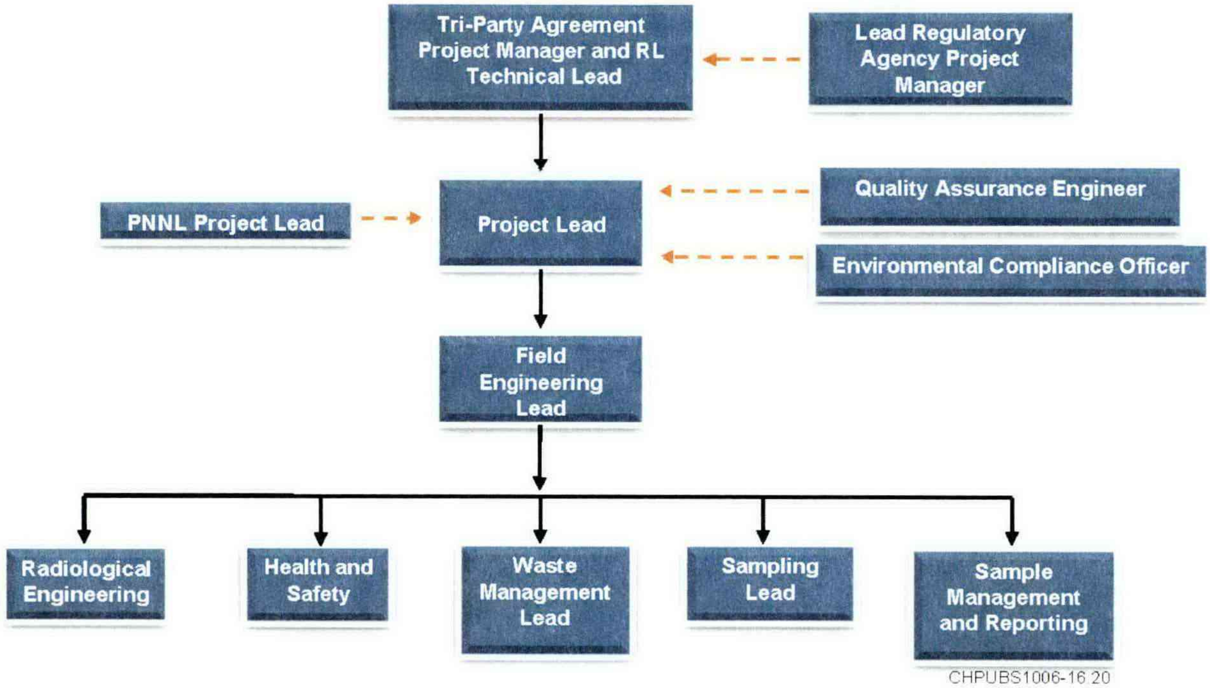
A project field schedule will be developed and provided separately, outside of this TTP. This working schedule may be modified as necessary.

15 Project Management

The following sections address the basic aspects of project management, ensuring that the project has defined goals, the project team understands the goals and approaches used, and the planned outputs are appropriately documented. Project management roles and responsibilities discussed in this Chapter apply to the major activities covered under the TTP.

15.1 Project and Task Organization

CHPRC is responsible for planning and managing all project activities. The following sections describe the project organization as shown in Figure 25. PNNL will provide technical design and direction for the study, while CHPRC personnel will be responsible for the physical implementation, health and safety, and the sampling and characterization tasks.



RL = U.S. Department of Energy, Richland Operations Office
Tri-Party Agreement = Ecology et al, 1989a, *Hanford Federal Facility Agreement and Consent Order*

Figure 25. Phytoextraction Treatability Test Organization

15.2 Functional Element Leads

The project lead maintains a list of individuals or organizations as points of contact for each functional element listed in Figure 25. For each functional primary contractor role, a corresponding oversight role exists within DOE-RL.

Lead Regulatory Agency Project Manager. The Lead Regulatory Agency (EPA) has assigned project managers responsible for overseeing the cleanup projects and activities. EPA has approval authority as the lead regulatory agency for the work being performed under this TTP. EPA will work with the U.S. Department of Energy, Richland Operations Office (RL) to resolve concerns regarding the work, as described in this TTP in accordance with the Tri-Party Agreement (Ecology et al., 1989).

Tri-Party Agreement Project Manager and RL Technical Lead. The Tri-Party Agreement Project Manager is responsible for authorizing RI/FS activities for the 100 Area Operable Units. The Tri-Party Agreement Project Manager also is responsible for obtaining lead regulatory agency approval of the TTP that authorizes the activities under the Tri-Party Agreement (Ecology et al., 1989). The RL technical lead is responsible for overseeing the contractor in performing the work scope, working with the contractor and the regulatory agencies to identify and work through issues, and providing technical input to the Tri-Party Agreement Project Manager.

Project Lead. The project lead is responsible for managing field activities, subcontracted tasks, and for ensuring the project file is properly maintained. The project lead ensures that the test plan design requirements are converted into field instructions (e.g., work packages) providing specific direction for field activities. The project lead works closely with the field engineer lead, QA, Health and Safety, the drilling lead, and the sampling lead to integrate these and other lead disciplines in planning and implementing the work scope. The project lead maintains a list of individuals or organizations filling each of the functional elements of the project organization (Figure 25). In addition, the project lead is responsible for version control to ensure that personnel are working to the most current job requirements. The project lead also coordinates with RL and the task leads on test plan implementation and sampling activities. The project lead supports RL in coordinating sampling activities with the regulators.

PNNL Project Lead. The PNNL project lead is responsible for the study design and technical input. The PNNL project lead will prepare the test plan design requirements and assist the project lead in converting the design into field instructions. The PNNL project lead will also direct the test results evaluation process and be responsible for preparing the data analysis and interpretation.

Environmental Compliance Officer. The environmental compliance officer provides technical guidance, direction, and acceptance of project and subcontracted environmental work and develops appropriate mitigation measures with a goal of minimizing adverse environmental impacts. The environmental compliance officer also reviews plans, procedures, and technical documents to ensure that environmental requirements have been addressed; identifies environmental issues affecting operations and develops cost-effective solutions; and responds to environmental and regulatory issues or concerns raised by RL and/or the regulatory agencies. The environmental compliance officer also may oversee project implementation for compliance with applicable internal and external environmental requirements.

Quality Assurance Engineer. The QA point of contact is matrixed to the project lead and is responsible for QA issues on the project. Responsibilities include, as appropriate, overseeing implementation of the project QA requirements; reviewing project documents, including data needs summary reports, field sampling plan, and the quality assurance project plan; and participating in QA assessments of sample collection and analysis activities. The QA point of contact must be independent of the unit generating the data.

Field Engineering Lead. The field engineering lead provides technical guidance and direction of project and subcontracted work. The field engineering lead also reviews plans, procedures, and technical documents to ensure technical requirements have been addressed, identifies potential issues affecting operations, and develops cost-effective solutions. The field engineering lead oversees implementation of subcontractor tasks such as well installation and apatite injection.

Waste Management Lead (Waste Coordinator). The waste management lead communicates policies and procedures and ensures project compliance for storage, transportation, disposal, and waste tracking in a safe and cost-effective manner. In addition, Waste Management is responsible for identifying waste management sampling and characterization requirements to ensure regulatory compliance, interpreting the characterization data to generate waste designations and profiles, and preparing and maintaining other documents that confirm compliance with waste acceptance criteria.

Sampling Lead. The sampling lead has overall responsibility for planning, coordinating, and executing sampling activities. Specific responsibilities include converting the sampling design requirements into field task instructions to provide specific direction for field activities, as well as directing training, mock-ups, and practice sessions with field personnel to ensure the sampling design is understood and can be performed as specified. The sampling lead also communicates with the field engineering lead to identify field constraints or emergent conditions affecting sampling design or execution, directs the procurement and installation of materials and equipment needed to support fieldwork, and prepares data packages. The shipping lead reports to the sampling lead for shipment authorization. No sample material will be transported on or off the Hanford Site without permission from an authorized shipper or designee.

Radiological Engineering. The Radiological Engineering lead is responsible for the radiological/health physics support within the project. Specific responsibilities include conducting as low as reasonably achievable (ALARA) reviews, exposure and release modeling, and radiological controls optimization for work planning. In addition, the Radiological Engineering lead identifies radiological hazards and implements appropriate controls to maintain worker exposures ALARA (e.g., requiring personal protective equipment). The Radiological Engineering lead also interfaces with the project Health and Safety contact, and plans and directs radiological control technician support for activities.

Sample Management and Reporting. Sample Management and Reporting coordinates laboratory analytical work, ensuring the laboratories conform to Hanford Site internal laboratory QA requirements, or their equivalent, as approved by DOE, EPA, and Ecology. Sample Management and Reporting receives analytical data from the laboratories, performs data entry into Hanford Environmental Information System, and arranges for data validation. Sample Management and Reporting is responsible for informing the field engineering lead of any issues reported by the analytical laboratory. Sample Management and Reporting develops and oversees the implementation of the letter of instruction to the analytical laboratories, oversees data validation, and works with the project lead to prepare a characterization report on the sampling and analysis results.

The Sample Management and Reporting organization is also responsible for performing the data needs process, or equivalent. Additional related responsibilities include developing the SAP, including documenting the data needs and the sampling design, preparing associated presentations, resolving technical issues, and preparing revisions to the SAP. Samples collected in the field and released to the River Corridor Closure Contractor for shipping and analysis, as well as the resulting data, will be managed in accordance with applicable procedures and work plans.

Laboratories. The laboratories analyze samples in accordance with established procedures, provide necessary sample reports, and explain results in support of data validation. The laboratories must meet site-specific QA requirements and must have an approved QA plan in place.

Health and Safety. Health and Safety is responsible for coordinating industrial safety and health support for the project through health and safety plans, job hazard analyses, and other pertinent safety documents required by federal regulation or by internal primary contractor work requirements. In addition, Health and Safety assists project personnel in complying with applicable health and safety standards and requirements. Health and Safety coordinates with Radiological Engineering to determine personal protective clothing requirements.

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Appendix A

Phytoextraction Treatability Test Sampling and Analysis

A1 Introduction

This appendix describes the process sampling and analysis requirements to monitor and evaluate the effectiveness of the 100-NR-2 OU Phytoextraction treatability test.

A1.1 Test Data Needs and Analytes

Project-specific data needs and technology performance standards for sampling and analysis were determined during development of the treatability test plan. Refer to Chapter 4.0 of the Treatability Test Plan for a discussion of the test objectives and performance criteria.

Sampling during the test will include a one-time initial sampling of the sediment below selected planting sites and an annual collection of plant biomass (stems and leaves).

Samples of sediment and plant tissue (stems and leaves) collected as part of the treatability test will be assayed for Sr-90 content using chemical extraction and liquid scintillation. These data will provide information on the effectiveness of the technology's performance. The analytical performance requirements for analytes, including the analytical method and required detection limits, are provided in Section A2.

A1.2 Project Schedule

An exact schedule for the project will depend upon the approval date, as this is a biological effort and requires a series of complete growing seasons over an extended period of two to three years. Actual construction of the plot (fencing, walkways, instrumentation) sediment sampling, and placement of the plants would occur in the fall of 2010 (FY 2010 and 2011). Sediment analysis would take place during November 2010 to January 2011. An initial annual report would be produced in January 2011. The first harvest of new-growth biomass (stems and leaves) would occur in the September 2011 to October 2011 timeframe with the completion of tissue analysis and production of a second annual report by January 2012. This would be followed by similar events in September 2012 to January 2013 (second harvest) and September 2013 to January 2014 (third harvest). A final report for the Treatability Test will be produced by January of 2014. If during the test there is a failure to meet the requirements for decision points described in Section 5.2.7, the test will be terminated and the site restored.

A2 Quality Assurance Project Plan

This section describes the applicable quality requirements and controls. Sections 6.5 and 7.8 of the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) (Ecology et al., 1989), require that the U.S. Department of Energy (DOE) conduct quality assurance (QA)/quality control (QC) and sampling and analysis activities in accordance with EPA/240/B-01/003; therefore, this quality assurance project plan (QAPjP) is organized in accordance with the QA elements specified in EPA/240/B-01/003. The QAPjP is divided into four sections that correspond to checklist sections and describe the quality requirements and controls applicable to this investigation.

This QAPjP complies with the following requirements:

- DOE/RL-96-68, *Hanford Analytical Services Quality Assurance Requirements Document* (HASQARD)
- DOE O 414.1C, *Quality Assurance*

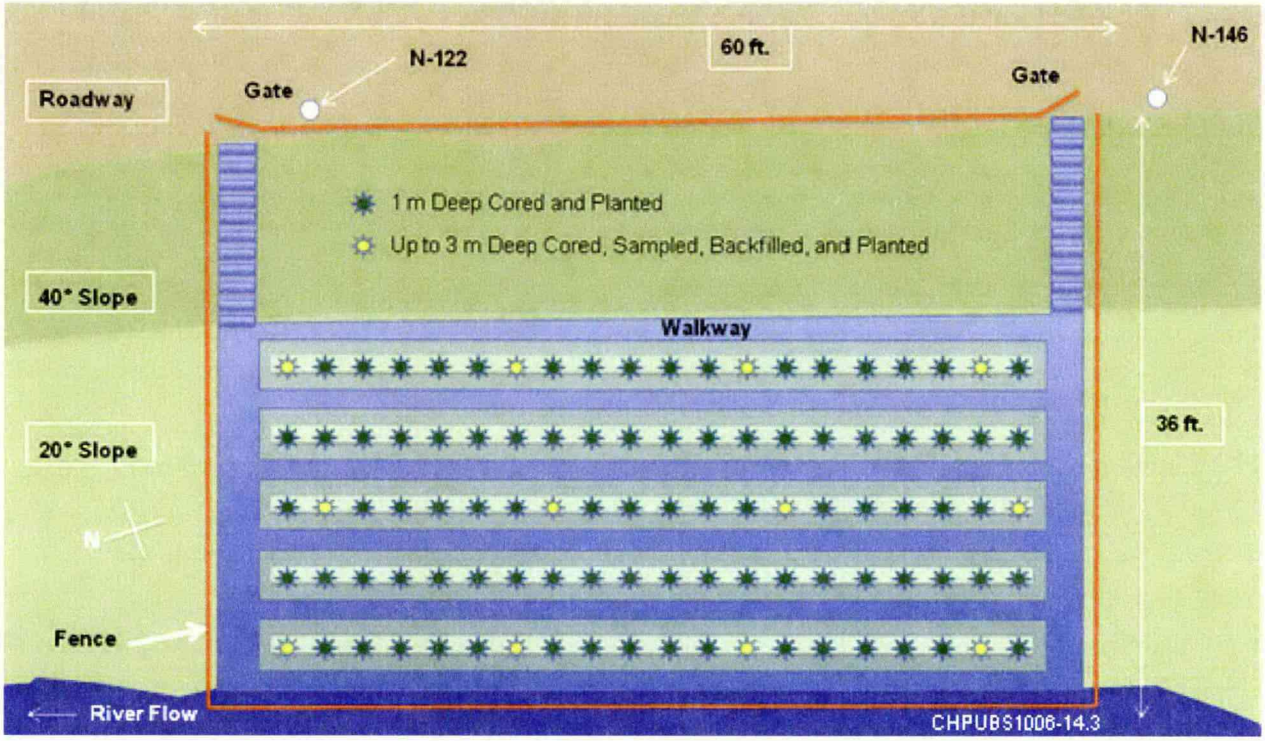

Figure A-1. Diagram Showing Potential Locations of 3 m (9.8-ft) Deep Cored Samples Within the Planting Grid

A2.1.3.2 Accuracy

Accuracy is an assessment of the closeness of the measured value to the true value. Strontium-90 is the target analyte. Instruments are calibrated on a daily basis and blanks (non-radioactive willow tissue and Hanford sediment) and spiked samples will be counted concurrently with the samples.

A2.1.3.3 Comparability

Comparability expresses the confidence with which one data set can be compared to another. Data comparability will be maintained by using standard procedures, uniform methods, and consistent units.

A2.1.3.4 Completeness

Table A-2 identifies the test sample analytes and analytical performance requirements. For sampling of sediment and plant tissue, Sr-90 is the primary analyte for technical evaluation. The analytical data set for the sampling will be considered incomplete if these are not included.

The determination of analytes for waste characterization will be made in accordance with a separate data quality objective process, which is outside the scope of this SAP. Consequently, completeness of the analytical data set for this purpose is not a consideration for this SAP.

A2.1.3.5 Precision

Precision is a measure of the data spread when more than one measurement exists of the same sample. Precision can be expressed as the relative percent difference (RPD) for duplicate measurements, or relative standard deviation for triplicates. Analytical precision for laboratory analyses is included in Table A-2.

A2.1.4 Special Training Requirements and Certification

The Environmental Safety and Health training program provides workers with the knowledge and skills necessary to execute assigned duties safely. CHPRC field personnel typically will have completed the following training before starting work:

- Occupational Safety and Health Administration 40-Hour Hazardous Waste Worker Training and Supervised 24-Hour Hazardous Waste Site Experience
- Eight-Hour Hazardous Waste Worker Refresher Training (as required)
- Hanford Site General Employee Training
- Radiological Worker Training (as required)

PNNL field and laboratory personnel will have completed appropriate training as defined in the PNNL HDI (How Do I) index before starting work. These may include:

- Hanford Site General Employee Training
- Radiation Worker Training
- Hazardous Waste Training

A graded approach is used to ensure that workers receive a level of training commensurate with their responsibilities in compliance with applicable DOE orders and government regulations. Specialized employee training includes pre-job briefings, on-the-job training, emergency preparedness, plan-of-the-day instructions, and facility/work site orientations.

A2.1.5 Documentation and Records

Field sampling and laboratory analytical documentation will be in accordance with contractor procedures and standard industry practices. Work products resulting from sampling and analysis may be included as documents and records, including the following:

- Laboratory data packages
- Verification and validation report

Both hardcopy and electronic versions of the record deliverables will be provided. Data files will be in an American Standard Code for Information Interchange (ASCII) -compatible format. The OU project manager is responsible for ensuring that project personnel are working to the current version of this SAP.

Data collected during field activities may be recorded electronically and/or in bound logbooks with sequentially numbered pages. Electronically recorded data shall include all pertinent information necessary to uniquely identify the information, including date, time, units, and location (if relevant). When logbooks are used, each new test day shall be identified by the date at the top of the logbook page. Each new entry will be designated by a time-of-day entry and start on a new line; data of sufficient detail will be entered to describe fully the activity or data being logged. At the conclusion of each day's activities, the logger will provide his/her initials at the end of the log for that day and place a diagonal line across the remaining unused page for that day's activities. All entries will be recorded in the logbook or on data collection sheets using waterproof, non-smear ink. Calibration data for monitoring/measuring equipment will be recorded in the logbooks. Photographs/digital/video images will be taken and noted in the logbook for reference and will then be cataloged and retained for future reference. Errors will have a line drawn through them, followed by the correction, initials of the person making the change, and the date.

A2.2 Data Generation and Acquisition

The following subsections present the requirements for sampling methods, sample handling and custody, analytical methods, and field and laboratory QC. The requirements for instrument calibration and maintenance, supply inspections, and data management are also addressed. The sampling design is presented in Section A3 of this SAP.

The field team lead is responsible for ensuring that all field procedures are followed completely and that field-sampling personnel are adequately trained to perform sampling activities under this SAP. The field team lead must document all deviations from procedures or other problems pertaining to sample collection, chain-of-custody, sample analytes, sample transport, or noncompliant monitoring. As appropriate, such deviations or problems will be documented in the file logbook or in nonconformance report forms in accordance with internal corrective action procedures. The field team lead or project manager is responsible for communicating field corrective action requirements and for ensuring that immediate corrective actions are applied to field activities.

A2.2.1 Sample Preservation, Containers, and Holding Times

Suggested sample container requirements are specified in Table A-1 for test sediment samples. The final container type and volumes will be provided on the sampling authorization form and the chain-of-custody form. This SAP defines a "sample" as a filled or partially filled sample container for a specific location.

Table A-1. Sample Container, Preservation, and Holding Time Guidelines

Sample Type	Containers		Volume (mL)	Preservation Requirement	Holding Time
	Number	Type			
Sediment Cores Sr-90 Content	2	M/P	2,000	Cool 4°C until dried	Indefinite
Plant Tissue Sr-90 Content	2	Paper/P/G	500	Cool 4°C until dried and ground, then stored in glass jars	Indefinite

M = metal cans
P = plastic bags
Paper = paper bags
G = glass jars

A2.2.2 Sampling Methods Requirements

Sampling associated with this SAP will be performed in accordance with established sampling practices and requirements pertaining to sample collection, collection equipment, and sample handling. Procedures from the contractor (or its approved subcontractor) will be used for sampling and should be in accordance with Section A3.3 and as outlined in HASQARD QA requirements (DOE/RL-96-68)and the applicable procedures for the sampling activities listed in this SAP.

A2.2.3 Sampling Identification

A sample and data-tracking database will be used to track the samples from the point of collection through the laboratory analysis process. The Hanford Environmental Information System (HEIS) database is the repository for laboratory analytical results. The HEIS sample numbers will be issued to the sampling organization for this project, and the numbers are to be carried through the laboratory data-tracking system.

A2.2.4 Sample Handling, Shipping, and Custody Requirements

The processes followed for sample handling, shipping, and custody requirements will be in accordance with those presented in Section A3.4.

A2.2.5 Laboratory Sample Custody

Sample custody during laboratory analysis will be addressed in the applicable laboratory's standard operating procedures. Laboratory custody procedures will ensure that sample integrity and identification are maintained throughout the analytical process.

A2.2.6 Analytical Methods Requirements

Table A-2 identifies the analytical methods and analytical performance requirements for sediment and plant tissue analysis.

Table A-2. Analytical Performance Requirements for Samples

Analyte	Analytical Method	Detection Limit (pCi/g dry wt.)	Accuracy Requirement (%)	Precision Requirement (%)
Chemical Analyses				
Sr-90—Bank Sediment	Sr-90 Chemical extraction	5	80-120	≤20
Sr-90—Plant Tissue	Sr-90 Chemical extraction	5	80-120	≤20

A2.2.7 Quality Control Requirements

Laboratory instruments shall be tested, inspected, and maintained. Measurement equipment must be inspected before use. Tags will be attached to analytical instruments, noting the date when the instrument was last calibrated and the calibration expiration date. Measurement and testing equipment used in the laboratory directly affecting the quality of analytical data will be subject to preventive maintenance measures to ensure that measurement system downtime is minimized.

Laboratories and onsite measurement organizations must maintain and calibrate equipment. Calibration of laboratory instruments will be performed in a manner consistent with SW-846, *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods, Third Edition; Final Update IV-B*, or with auditable HASQARD and contractual requirements. Calibration of radiological field instruments (if used) will be performed by radiologicial control technicians (RCTs). The data will be reported as accepted, rejected, or qualified. Calibration is conducted with certified equipment and/or standards with a known valid relationship to nationally recognized performance standards. If no such standards exist, the basis for calibration shall be documented.

A2.2.8 Inspection of Consumable Supplies

Consumables, supplies, and reagents will be reviewed in accordance with the current requirements of SW-846 and will be appropriate for use. Potential contamination is monitored by QC samples and laboratory blanks.

A2.2.9 Instrument and Equipment Testing, Inspection, and Maintenance

Equipment used for collection, measurement, and testing should meet the applicable standards (e.g., ASTM) or have been evaluated as acceptable and valid in accordance with the procedures, requirements, and specifications. The Sampling Lead will ensure that the data generated from instructions using a software system are backed up and/or downloaded regularly. Software configuration will be acceptance-tested before use in the field.

Measurement and testing equipment used in the field or in the laboratory that directly affects the quality of analytical data will be subject to preventive maintenance measures to ensure minimization of measurement system downtime. Laboratories and onsite measurement organizations must maintain and calibrate their equipment. Maintenance requirements (such as documentation of routine maintenance) will be included in the individual laboratory and the onsite organization QA plan or operating procedures, as appropriate. Maintenance of laboratory instruments will be performed in a manner consistent with three- and four-digit EPA methods (EPA-600/4-79-020; EPA-600/R-94-111; SW-846), or with auditable Hanford Site and contractual requirements. Consumables, supplies, and reagents will be reviewed in accordance with SW-846 requirements and will be appropriate for their use.

A2.2.10 Instrument and Equipment Calibration and Frequency

Analytical laboratory instruments and measuring equipment are calibrated in accordance with the laboratory's QA plan.

The Sampling Lead is responsible for ensuring that field equipment is calibrated appropriately. Onsite environmental instruments are calibrated in accordance with the manufacturer's operating instructions, internal work requirements and processes, and/or work packages that provide direction for equipment calibration or verification of accuracy by analytical methods. The results from all instrument calibration activities are recorded in logbooks and/or work packages. Either hard copy or electronic calibration records are acceptable.

Calibrations must be performed as follows:

- Prior to initial use of a field analytical measurement system
- At the frequency recommended by the manufacturer or procedure, or as required by regulations
- Upon failure to meet specified QC criteria

Field instrumentation, calibration, and QA checks will be performed in accordance with the following:

- Calibration of radiological field instruments on the Hanford Site is performed by Pacific Northwest National Laboratory, as specified in their program documentation.
- Daily calibration checks will be performed and documented for each instrument used to characterize areas under investigation. These checks will be made on standard materials sufficiently like the matrix under consideration for direct comparison of data. Analysis times will be sufficient to establish detection efficiency and resolution.
- Standards used for calibration will be traceable to nationally or internationally recognized standard agency source or measurement system, if available.

A2.2.11 Nondirect Measurement

Nondirect measurements include data obtained from sources such as computer databases, programs, literature files, and historical databases. Nondirect measurements will not be evaluated as part of this activity.

A2.2.12 Data Management

Data resulting from the implementation of this SAP will be stored in the HEIS database. Reports and supporting analytical data packages will be subject to final technical review by qualified reviewers before submittal to the regulatory agencies or inclusion in reports or technical memoranda. Electronic data access, when appropriate, will be through a computerized database (e.g., HEIS). Where electronic data are not available, hardcopies will be provided in accordance with Section 9.6 of the Tri-Party Agreement (Ecology et al, 1989).

A2.2.13 Laboratory Quality Control

Laboratory Quality control will be that specified in *The Columbia River Protection Supplemental Technologies Quality Assurance Project Plan* (PNNL-16340).

A2.2.14 Field Documentation

Field documentation shall be maintained in the form of chain-of-custody/sample analysis request forms and logbook entries.

A2.3 Assessment/Oversight

Routine evaluation of data quality described for this project will be documented and filed with the data in the project file. The OU project manager (or designee) and/or the field team lead will monitor field activities for this SAP. The OU project manager retains overall responsibility for sampling, but may delegate specific responsibilities to the field team lead or other appropriate contractor staff.

A2.3.1 Assessments and Response Action

Random surveillance and assessments may be conducted to verify compliance with the requirements outlined in this SAP, project work packages, the QAPjP, procedures, and regulatory requirements. Deficiencies identified by these assessments will be reported. The project's QA organization coordinates corrective actions/deficiencies in accordance with the contractor's QA program. When appropriate, corrective actions will be taken by the OU project manager (or designee). The project manager is responsible for implementing corrective actions and verifying their completeness and effectiveness.

A2.3.2 Reports to Management

Management will be made aware of deficiencies identified by self-assessments, corrective actions from environmental compliance officers, and findings from QA assessments and surveillances.

A2.4 Data Review, Verification, Validation, and Usability Requirements

Samples taken will be loaded into a database (e.g., HEIS), and verified (Section A2.4.1). At the direction of the OU project manager (or designee), analytical data packages will be subject to final technical review by qualified personnel before submittal to the regulatory agencies or inclusion in reports. Electronic data access, when appropriate, will be via a database (e.g., HEIS). Where electronic data are not available, hardcopies will be provided in accordance with Section 9.6 of the Tri-Party Agreement (Ecology et al, 1989).

A2.4.1 Data Verification and Usability Methods

Data review and verification are performed by the laboratory to confirm that sampling and chain-of-custody documentation are complete. This review shall include linking sample numbers to specific sampling locations, reviewing sample collection dates and sample preparation and analysis dates to assess whether holding times have been met, and reviewing QC data to determine whether analyses have met the data quality requirements specified in this SAP.

A2.4.2 Resolution of Analytical System Errors

Errors reported by the laboratories are reported to the Sample and Data Management organization project coordinator, who initiates a sample disposition record in accordance with contractor procedures. This process is used to document analytical errors and to establish resolution with the OU project manager.

A2.4.3 Data Validation

Data validation may be performed by the Sample and Data Management organization and/or by a party independent of both the data collector and the data user.

A2.4.4 Data Quality Assessment

The data quality assessment process compares completed field/laboratory activities to those in corresponding documents and provides an evaluation of the resulting data. The purpose of the data assessment is to determine if quantitative data are of the correct type and are of adequate quality and quantity to meet the project data quality objectives. The assessment will be consistent with the data quality assessment process in EPA/240/B-06/002, *Data Quality Assessment: A Reviewer's Guide*, and EPA/240/B-06/003, *Data Quality Assessment: Statistical Tools for Practitioners*.

Method blanks and any field/equipment blanks will be compared to the data to assess contamination.

A3 Field Sampling Plan

This field-sampling plan identifies the activities for performance of test sampling as well as field and laboratory analysis.

A3.1 Sampling Objectives

This SAP provides for sampling to meet treatability test objectives and technology performance requirements. The duration of the test is approximately 36 months. The primary objective of sampling is to provide sufficient analytical data to determine the effectiveness of the technology in meeting performance requirements. The data will also provide design and performance information necessary to facilitate full-scale implementation of Sr-90 phytoextraction. Samples of the 100-NR-2 shoreline within the proposed plot will be collected prior to willow planting. After planting and growth, the trees will be harvested for new growth stems and leaves. Samples will undergo Sr-90 analysis as identified in Table A-2.

A3.2 Sampling Design

This section identifies the design for test sampling and identifies sample locations, sample intervals, sampling processes, target analytes and parameters, and analytical methods used to meet project-sampling objectives.

A3.3 Sampling Locations and Frequencies

Procedures from the contractor (or its approved subcontractor) will be used for sediment sampling. Samples locations within the plot are shown in Figure A-1. Sediment sampling will occur just prior to planting of the willows to determine the baseline of contaminant (Sr-90) distribution below the plants.

Upon completion of each growing season, the plants will be harvested. Harvesting will occur in the fall (late September to early October). An exact date cannot be determined as the maturity (senescence status) of the plant depends on environmental factors such as water, temperature, and sunlight. Specific details are given in Chapter 5.2.6 in the main document.

A3.4 Field-Specific Collection Requirements

Treatability test sampling under this SAP will be performed in accordance with site sampling procedures using appropriate sampling equipment.

A3.4.1 Sample Identification

The process samples shall be uniquely numbered and the sample number and location shall be documented. Each sample and chain-of-custody form must be identified by sample number and sampling authorization form number.

A sample tracking database will be used to track the samples through the collection and laboratory analysis process. The HEIS database is the repository for the laboratory analytical results. The HEIS sample numbers will be issued to the sampling organization for this project. The radiological and physical properties of each sample will be identified and labeled with a unique HEIS sample number. The sample location, depth, and corresponding HEIS numbers will be documented in the sampler's field logbook. Each sample container will be labeled with the following information, using a waterproof marker on firmly affixed, water-resistant labels:

- Sampling authorization form number
- HEIS number
- Sample collection date and time
- Analysis required

A3.4.2 Field Sample Logbook

Information pertinent to sampling and analysis will be recorded in field checklists and logbooks (PNNL Laboratory Record Books) in accordance with existing sample collection protocols. The sampling team will be responsible for recording relevant sampling information. Entries made in the logbook will be dated and signed by the individual making the entry. Program requirements for managing the generation, identification, transfer, protection, storage, retention, retrieval, and disposition of records will be followed.

A3.4.3 Sample Custody

Sample custody will be maintained in accordance with existing Hanford Site protocols. The custody of samples will be maintained from the time that samples are collected until ultimate disposal of the samples, as appropriate. A chain-of-custody record will be initiated in the field at the time of sampling and will accompany each set of samples shipped to the laboratory. Sample shipping procedures will be followed throughout sample shipment. Each chain-of-custody form will include the sample identification number. The analyses requested for each sample will be indicated on the accompanying chain-of-custody form.

Chain-of-custody procedures will be followed throughout sample collection, storage, transfer, analysis, and disposal to ensure that sample integrity is maintained. Each time the responsibility for the custody of the sample changes, the new and previous custodians will sign the record and note the date and time. A custody seal (i.e., evidence tape) will be affixed to the lid of each sample jar. The container seal will be inscribed with the sampler's initials and the date. Sample custody during laboratory analysis will be addressed in the applicable laboratory's standard operating procedures.

A3.4.4 Sample Shipping

Samples will be transported after authorization from the S&GRP-authorized shipper. If the samples have a medium or high risk of containing radiological material, radiological surveys will be required. If radiological materials are not anticipated, RCT surveys may not be required if the RCT field readings show no activity above background. As applicable, the RCT will measure the radiological activity on the outside of the sample container (through the container) and will document the highest contact radiological reading in millirem per hour. This information, along with other data, will be used to select proper packaging, marking, labeling, and shipping paperwork in accordance with U.S. Department of Transportation regulations (49 CFR, "Transportation").

A3.4.5 Management of Waste

Chapter 11 of the Treatability Test Plan describes waste management.

A4 Health and Safety Plan

Chapter 10 of the Treatability Test Plan describes project health and safety requirements.

A5 References

10 CFR 830, "Nuclear Safety Management," Subpart A, "Quality Assurance Requirements," *Code of Federal Regulations*. Available at: http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&rgn=div6&view=text&node=10:4.0.2.5.26.1&idno=10.

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